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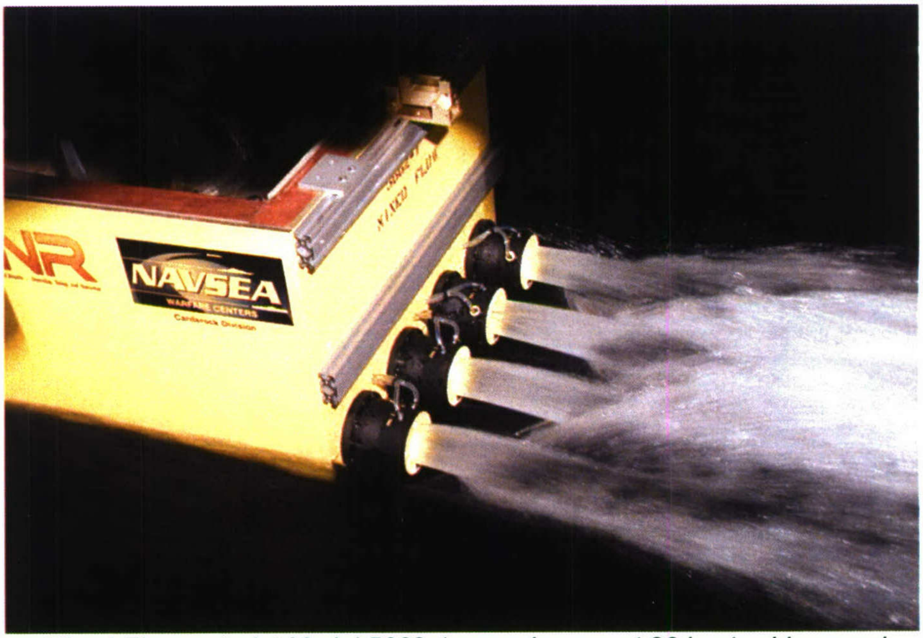
Axial Waterjet (AxWJ) Model 5662 and Mixed-Flow Waterjet (MxWJ) Model 5662-1: Comparisons of Resistance and Model-Scale Powering with Propulsion Nozzle Designs

By
Dominic S. Cusanelli, Scott A. Carpenter, and Anne Marie Powers



Mixed-Flow waterjet Model 5662-1 powering run at 36 knots ship speed

NSWCCD-50-TR–2007/076 Axial Waterjet (AxWJ) Model 5662 and Mixed-Flow Waterjet (MxWJ) Model 5662-1: Comparisons of Resistance and Model-Scale Powering with Propulsion Nozzle Designs

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14. ABSTRACT
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Bare hull effective powers at three displacement conditions, and appended effective powers at design displacement, were determined and compared for the two waterjet variants, and then compared to the JHSS baseline shaft & strut (BSS) hull.

Model-scale rotor force measurements were recorded and compared for both the AxWJ and the MxWJ under power. These tests were conducted on both models with waterjet nozzles specifically designed for propulsion.

A detailed powering analysis derived from the AxWJ and MxWJ model resistance and

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rotor force measurements, as well as LDV velocity measurements and pressure tap measurements, will be reported in a separate document. This future document will address full-scale AxWJ and MxWJ powering predictions and comparisons to the JHSS baseline BSS.

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ABSTRACT

This report is a partial documentation of two series of model-scale experiments conducted 5/07-6/07, comparing the Axial Waterjet (AxWJ) Model 5662 and the Mixed-Flow Waterjet (MxWJ) Model 5662-1, two waterjet propelled variants of the Joint High Speed Sealift (JHSS) hull platform. This document contains calm water resistance and model-scale powering test results.

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ADMINISTRATIVE INFORMATION

Funding for the evaluation of the Axial Waterjet on the JHSS hull platform was through the Office of Naval Research, "ONR Compact High Power Density Waterjet FNC Program", Project Manager Dr. Ki-Han Kim (ONR 331), and for the Mixed-Flow Waterjet evaluation was through the US Navy's Sealift R&D Program, managed through the Strategic & Theater Sealift Program Office PMS 385. The Joint High Speed Sealift (JHSS) Program Project Manager is William Davison (PMS 385). The JHSS Hydro Working Group (HWG), which includes representatives from NAVSEA, NSWCCD, ONR and CSC, coordinates all hydrodynamic, propulsion, hullform, and structural loads R&D for these combined programs.

Model tests were conducted at the David Taylor Model Basin, Naval Surface Warfare Center, Carderock Division Headquarters, (NSWCCD), by the Resistance & Powering Division (Code 5200) and the Propulsion and Fluid Systems Division (Code 5400), under work unit numbers 06-1-5030-105/6, 06-1-2123-404/5 and 07-1-2125-145.

INTRODUCTION

The Joint High Speed Sealift (JHSS) was a potential FY12 ship acquisition sponsored by OPNAV N42. The program was originally designated the Rapid Strategic Lift Ship (RSLS) as outlined in "Rapid Strategic Lift Ship Feasibility Study Report" [Ref. 1]. In the "Joint High Speed Sealift (JHSS)" presentation [Ref. 2], the ship's capability was broadly described as being able to "Embark design payload, transport it 8,000 nm at 36 knots or more, and disembark it to a seabase or shore facility". Under the auspices of the aforementioned Program Offices, three different types of propulsion systems are to be evaluated on the JHSS parent hull platform: (1) conventional open propellers on shafts and struts, (2) waterjet propulsion, and (3) pod propulsion.

The entire evaluation of waterjet propulsion on the JHSS hull platform is to include the construction and testing of two model hulls, the Axial Waterjet (AxWJ) Model 5662, and the Mixed-Flow Waterjet (MxWJ) Model 5662-1. The extensive testing planned for the two waterjet models, which will extend over a period of more than eight months, as well as details pertaining to the design of the waterjets, will be summarized in a single volume after the

conclusion of the test programs and analysis period. In the interim, several reports of smaller scope, documenting the numerous series of experiments, will be prepared.

This report is the documentation of the model-scale evaluation to determine the relative performance merits of the Axial Waterjet (AxWJ) Model 5662 versus the Mixed-Flow Waterjet (MxWJ) Model 5662-1. The calm water resistance and powering tests, reported herein, were part of a large scope of testing conducted on the two waterjet hulls, which also included testing to define mass flow, velocities, and pressures within the waterjet system, and to determine added resistance and powering in waves. This report is intended to document only the following two series of model-scale calm water resistance and powering tests, conducted June-July, 2007:

(1) Axial Waterjet (AxWJ) Model 5662. This test series, outlined in Appendix A, Table A1, is the second iteration of such experiments conducted on this model.[1] The current test series was conducted with propulsion-designed nozzles. AxWJ data and analysis is presented in Appendix A.

(2) Mixed-Flow Waterjet (MxWJ) Model 5662-1. Initial resistance and powering test series on this model, outlined in Appendix B, Table B1, conducted with propulsion-designed nozzles. MxWJ data and analysis is presented in Appendix B.

BACKGROUND

The current model-scale waterjet experiments are an evaluation of the relative performance merits between an axial waterjet (AxWJ) and a mixed-flow waterjet (MxWJ), representing two different waterjet propulsion variants on the JHSS hull platform. Mixed-flow pumps, as used in most current commercially available waterjets, are mature technology. Fluid flow across the blades of a mixed-flow pump is both chord-wise and radial, hence the name. The radial component of flow necessitates an expansion of the diameter of the pump chamber aft of the rotor, prior to the contraction through the nozzle. Axial waterjet technology is in the early stages of commercial availability. In its simplest idealized terms, an axial pump is a "pump in a pipe" which requires no expansion aft of the rotor, because most of the fluid flow is chord-wise across the blades. Axial waterjets can be designed to a much smaller total diameter in comparison to a mixed-flow waterjet of equivalent power. Therefore, the relative size of the transom required to house the numerous waterjets required to propel the ship can be significantly reduced with the use of axial waterjets. The smaller transom size required of an axial waterjet propelled hull places it at a distinct advantage, in terms of low to medium speed resistance and power, in comparison to a mixed-flow waterjet propelled hull. The achievable full-scale pump efficiencies between axial and mixed-flow pumps is still being investigated.

Of important note, this model-scale waterjet evaluation will utilize surrogate waterjet pumps of identical design in both models. The model-scale hulls, waterjet installations and clearances reflect full-scale arrangements and spacings. This evaluation will therefore address only hullform associated relative performance merits between the two different waterjet propulsion configurations, and will not address issues relating to achievable pump efficiencies between axial and mixed-flow pumps.

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[1] Prior to this test series, experiments were conducted on AxWJ Model 5662 with an LDV nozzle design that incorporated large external structures to enclose water baths necessary to conduct Laser Doppler Velocimetry (LDV) measurements, as detailed by Cusanelli and Carpenter [Ref 3]. The current propulsion nozzles design avoids the flow impingement that was observed with the LDV nozzles.

Initial design expectations for the Axial Waterjet (AxWJ) and the Mixed-Flow Waterjet (MxWJ) JHSS hulls are as follows. Detailed comparisons between the two waterjet variants are presented in Appendix C.

(a) A decrease in bare hull and appended resistance (and by extension power) throughout most of the speed range, at equivalent displacement, is likely for the AxWJ over that of the MxWJ, as a result of the reduced volume and depth of transom.
(b) The greater transom volume of the MxWJ may become an advantage in terms of reduced resistance at very high speeds.
(c) Some decrease in propulsion efficiency may be a result of the reduced spacing between the pump inlets / waterjet intakes of the AxWJ over that of the MxWJ design.
(d) In comparison to the baseline shaft & strut hull, it is likely that neither waterjet-propelled hull will exhibit reduced powering at low to medium speeds, but both are expected to provide a reduction in power by the 39 knot top speed of interest.

HULL MODELS

Tests contained herein were conducted on two candidate waterjet-propelled propulsion model variants of the JHSS hull platform. The Axial Waterjet (AxWJ) is represented by Model 5662, presented in Appendix A, Figures A1-A5; and the Mixed-Flow Waterjet (MxWJ) is represented by Model 5662-1, presented in Appendix B, Figures B1-B5. Both were built of fiberglass to a linear scale ratio $\lambda = 34.121$, and LBP = 27.86 ft (8.5 m), and manufactured at NSWCCD. The AxWJ and MXWJ model scale ratios are equivalent to that of the JHSS Baseline Shaft & Strut (BSS) hullform Model 5653 [Ref. 4].

Differences Between Waterjet Hull Designs

In this particular application of waterjets to the JHSS hull platform, four high-powered, large-diameter waterjets were required to be housed in each transom variant. Each waterjet variant's transom, AxWJ and MxWJ, was designed to a relative minimum total volume required to house the four waterjets and associated hardware, while adhering to some basic arrangement and sizing criteria prescribed by the HWG.[2] Where possible, the waterjet design guidance was based upon existing commercial off-the-shelf (COTS) waterjet designs and arrangements.

[1] Waterjet Maximum Diameter was defined as the outer diameter (OD) of the mounting flange. A waterjet pump inlet diameter to maximum diameter ratio of 1:1.65 for the MxWJ was based on COTS Kamewa waterjets. A ratio of 1:1.20 was assumed for the AxWJ.
[2] Flange Clearance / Pump Inlet Spacing: To allow for flange clearance, mounting hardware, and adequate access to machinery, it was stipulated that the arrangements would require a minimum spacing (flange-to-flange clearance) of approximately 0.5m (1.64ft).
[3] Waterjet Submergence / Transom depth: To assure rotor priming, it was prescribed that, at minimum, half of the waterjet inlet diameter was to remain submerged when at even keel, design displacement.

Differences between the AxWJ and MxWJ stern design variants and arrangements are presented, in brief, in Table 1 and Figure 1, and in greater detail in Appendix C, Figure C1 and Table C1. Table dimensions are in full-scale ship feet, and depth, width, and volume correspond to design displacement (DES) of 36,491 tons.

[2] Electronic mail message "waterjet guidance" issued by E. Maxeiner (HWG Secretary), 10 May 2006.

Table 1. AxWJ and MxWJ stern design geometry comparison

JHSS Waterjet Full-Scale Design Criteria	AxWJ	MxWJ	AxWJ Δ%
Pump Inlet Diameter (ft)	9.84	9.19	+7%
[1] Waterjet Maximum Diameter (ft)	11.81	15.16	-22%
[2] Pump Inlet Spacing, Inbd-to-Otbd (ft)	13.94	16.80	-17%
Pump Inlet Clearance, Inbd-to-Otbd (ft)	4.92	7.81	-37%
Transom Width (ft)	56.61	69.13	-18%
[3] Transom Depth (ft)	6.88	8.78	-22%
Transom Volume aft of Station 15 (ft^3)	179100	208064	-14%

Table dimensions are Full-Scale

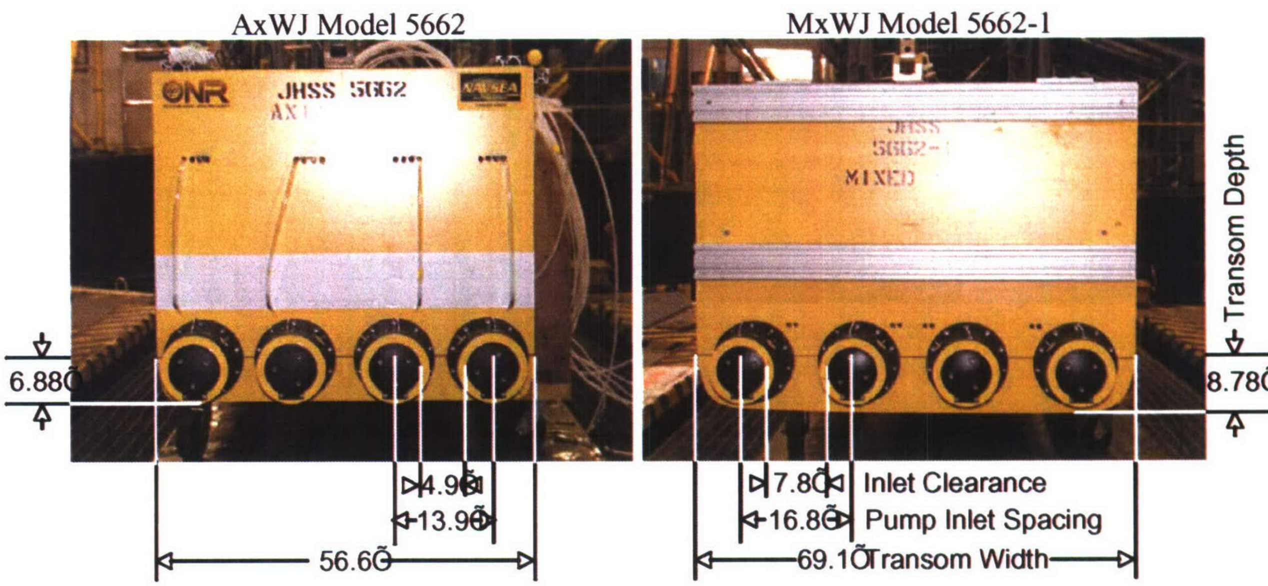

Fig. 1. AxWJ Model 5662 and MxWJ Model 5662-1, comparative photographs of stern designs with propulsion nozzles

Construction

The two waterjet models, AxWJ Model 5662 and MxWJ Model 5662-1, were constructed essentially as half-models, comprised of bow and stern half-sections separable at a part-line amidships at station 10, which allowed for the interchangeable stern half-models to be tested on the same bow half-model. Both stern half-models were manufactured from a single female wooden mold which was first cut and shaped to fabricate the AxWJ Model 5662, and then recut / reshaped to fabricate the MxWJ Model 5662-1. The stern half-models were built using a 3/8-inch fiberglass composite hull, decking, and bulkheads to reduce weight and cost.

A unique feature of waterjet stern half-models was their construction with cut-outs into which large waterjet stern plug assemblies were installed, Figure 2, which contained the waterjets and hardware mount points. Each stern plug assembly was manufactured in four sections using a stereolithography[3] apparatus (SLA), and joined together before being mated with their respective stern half-models.

[3] Stereolithography is rapid manufacturing / prototyping technology additive fabrication process utilizing a vat of liquid UV-curable photopolymer resin and a UV-laser to build parts a layer at a time. On each layer, the laser traces a part cross-section pattern on the surface of the liquid resin. Exposure to the UV-laser light solidifies the pattern traced on the resin and adheres it to the layer below.

Integrated features of each stern plug included:

- inlet and pump chamber geometry
- internal pressure tap passages
- fwd impeller shaft bearing mounts
- fastener and location holes
- LDV measurement hardware and windows mounts (AxWJ only)

Fig 2. Model 5662 waterjet stern plug assembly

The nozzle/stator assembly was also fabricated using the SLA process. Four individual nozzle/stators were manufactured for each model, Figure 3. For both models, the waterjet nozzle/stators were specifically designed for propulsion. Herein, these nozzle/stators will be referred to as propulsion nozzles. The propulsion nozzle design did not include steering or reversing buckets, which would be a necessary component of any full-scale waterjet installation. Each propulsion nozzle included:

- the nozzle
- integrated stator blades and hub
- rear impeller shaft bearing mount
- water passage for bearing cooling
- keil probe mounts

Fig3. Individual propulsion nozzle

Each waterjet stern half-model shared the usage of a single bow half-model (labeled as Model 5662). The bow half-model was of the identical design to that of the parent JHSS hull platform, and was manufactured from the same wooden female mold as JHSS baseline BSS Model 5653. The bow half-model was also built using a 3/8-inch fiberglass composite hull, decking, and bulkheads. The bow half-model included the installation of the Gooseneck Bulb (GB), selected as the optimal tested bow design from the JHSS BSS Series 1 tests [Ref 4].

The propulsion drive assemblies for both waterjet models utilized the identical components, instrumentation, and electronics. Between the two waterjet test series detailed herein, the entire propulsion drive assembly was removed from the first AxWJ model tested and installed almost in its entirety into the second MxWJ model (only the cross-connection shafts differed between the two installations). Both models utilized the identical machined composite impellers on the four impeller shafts, installed at the equivalent shaftline positions. In both models, the shafts were connected to the identical dynamometers (again, installed at the equivalent shaftline positions) for the measurement of thrust and torque on each impeller shaft.

Appendage Configurations

The bare hull configurations for both the AxWJ and MxWJ were represented at model-scale with the waterjet inlets (intakes) covered by thin galvanized metal plates cut to the shape of the inlets, and affixed to the model with white fairing tape. The propulsion nozzles were not installed, and in their place was another metal plate installed flush with the vertical transom, covering the waterjet exits, again faired with white tape.

The appended resistance experiments were conducted with the propulsion nozzles installed on the models, but with the waterjet inlets (intakes) remaining covered. In addition, when the

inlets were opened for powering tests, right-angle ("L" shaped) pitot tubes were installed under the hull at waterjet station 1.

To produce turbulent flow along the model, turbulence stimulator studs of 1/8-inch diameter by 1/10-inch height, spaced 1 inch apart, were affixed to the model approximately 2-inches aft of the stem, and continuing down to and around the bulb approximately 2 inches aft of the FP.

Model Inspections

Prior to the current test series, inspections of Models 5662 and 5662-1 were conducted with a laser tracker.[4] The complete model measurement report is reproduced in Appendix D. The measured model points were compared to the numeric hull surface representation CAD files from which the models were manufactured. The measured points and CAD file were aligned with emphasis placed on the hull surface below the design water line (DWL). Model surface tolerance of $\pm$ 2mm ($\pm$0.079 inch) was specified by the Code 5800 project (model test) engineer.

For AxWJ Model 5662, 99.6% of the measured points below the DWL fall within tolerance. For MxWJ Model 5662-1, 96.4% of the measured points below the DWL fall within tolerance. Both Models 5662 and 5652-1 far exceed the minimum standard for resistance and propulsion model manufacture (75% of the measured points within tolerance) set fourth for model acceptance by NSWCCD.

Instrumentation for Resistance and Powering

The linear bearing, floating platform "Cusanelli" tow post [Ref. 5], was utilized for the forward attachment point of the models to the towing carriage. Mechanical connection between the tow post and models was made through a double-axis gimbal assembly. When attached through the floating platform tow post system, the models are restrained in surge, sway, and yaw, but are free to pitch, heave, and roll. The location of each model tow point was approximately ship Station 5, parallel to, and at the same level as, the design waterline (DWL). For the aft attachment point, the standard 'grasshopper' bracket was utilized, attached at approximately ship Station 15. The counter weights and vertical arm were balanced, in place, so that the arm would not impart any vertical force on the models.

Model resistance (drag) measurements were collected using a DTMB 4-inch block gauge, of 100-lbf. capacity. Model side force measurements were collected with a DTMB 4-inch block gauge of 50-lbf. capacity. Side force is monitored at the tow post attachment point during calm water tests in order to maintain an essentially zero side force to insure zero yaw angle. Dynamic sinkage (defined as positive downward) was measured by wire potentiometers, which were located at the intersection of the deck line at approximately Station 2 forward and Station 16 aft.

The thrust and torque on all four rotor shafts were measured with Kempf and Remmer's (K&R) model R31 dynamometers, of 22-lbf. thrust (T) / 35-in-lbf. torque (Q) capacity. To insure equivalent shaft rotational speed (RPM), all four rotor shafts were driven through 1:1 drive ratio "T" gearboxes and mechanically coupled so that all shafts were powered by a single 19 hP constant-torque electric drive motor. Shaft rotation for all four rotors was inboard-over-the-top. A single electronic pulse counter system was used to measure shaft RPM.

Calibration of all instrumentation was performed prior to the tests in the NSWCCD Code 5200 calibration lab by D. Mullinix (CSC contractor).

Displacement, Trim, and Wetted Surface

Both AxWJ and MxWJ bare hull resistance tests were conducted at the three JHSS hullform displacement conditions, the design displacement (DES) of 36,491 tons, a light displacement

[4] Laser inspections were conducted by R. Lerner and A. M. Powers (Code 6530).

(LITE) of 32,841 tons representing a 10 percent reduction in displacement from design, and a heavy displacement (HVY) of 40,140 tons representing a 10 percent increase in displacement from design. Appended resistance tests and powering tests were conducted at only the DES displacement. All ballasting conditions were static even keel (zero trim).

Hull hydrostatic calculations were made for the AxWJ and MxWJ, at each displacement condition, using the Code 5200 program "Hydro". However, unbeknownst to the authors, prior to the test series two different electronic hull surface geometry file sets had been circulated. The first surface file set, from which the models had been constructed, did not include a centerline skeg. The second file set, from which all of the pre-test wetted surface calculations were derived, included a centerline skeg. This discrepancy was not discovered until well after the completion of this and the subsequent waterjet test series. Therefore, additional post-test analysis was required. Hull hydrostatics and ship/model parameters, reflecting the corrected values of wetted surfaces (corresponding to the model configuration without a centerline skeg), are presented for the AxWJ in Appendix A, Tables A2 and A3, and for the MxWJ in Appendix B, Tables B2 and B3.

Adjustments were made in the post-test re-analysis of the resistance and powering data to account for the absence of the skeg. Table 2 presents the ship hydrostatic values, in brief, utilized for the analysis presented herein, corresponding to the correct model configuration, as tested, without centerline skeg.

Table 2. AxWJ and MxWJ hydrostatics without skegs

	Design (DES)		Heavy (HVY)		Light (LITE)	
	AxWJ	MxWJ	AxWJ	MxWJ	AxWJ	MxWJ
LWL (ft)	979.4	980.2	948.5	949.4	981.6	981.9
WETTED SURFACE (ft^2)	96696	97372	100380	101083	92896	93620
DISPLACEMENT (tons)	36491	36491	40140	40140	32841	32841
DRAFT (ft)	28.3	27.8	30.1	29.6	26.5	26.1

WATERJET TEST RESULTS AND COMPARISONS

Test data and analysis for the Axial Waterjet (AxWJ) Model 5662 are presented in Appendix A, and for the Mixed-Flow Waterjet (MxWJ) Model 5662-1 are presented in Appendix B. Comparisons between AxWJ and MxWJ are presented in Appendix C.

The ship-model correlation allowance of $C_A = 0.0$ was recommended by NSWCCD Code 5200 based on the NAVSEA guidance as modified by more recent correlation allowance experience. The value of $C_A = 0.0$ was agreed upon by the JHSS Hull Working Group (HWG). Predictions are made for the full-scale AxWJ and MxWJ operating in smooth, deep, salt water, with a uniform standard temperature of 59°F.

All presented effective power predictions and rotor force measurements at ship propulsion point, for AxWJ and MxWJ models, have been adjusted to reflect the hull wetted surfaces corresponding to the model configurations without centerline skegs, as tested.

Bare Hull and Appended Resistance

Bare hull resistance experiments were conducted on AxWJ Model 5662 and MxWJ Model 5662-1, each at the three displacements, DES, HVY, and LITE. Tests were conducted across the speed range of 15 to 45 knots. Again, bare hull was represented with the waterjet inlets (intakes) and waterjet outlets sealed, and propulsion nozzles were not installed. The bare hull effective power (PE) predictions for the full-scale AxWJ, at three displacements, are presented and compared in Appendix A, Figure A6 and Tables A4-A6. Likewise, the bare hull PE predictions

for the full-scale MxWJ, at three displacements, are presented and compared in Appendix B, Figure B6 and Tables B4-B6. variants, MxWJ and AxWJ, are presented in Appendix C, Figures C2-C3 and Table C2, and summarized in Table 3 and Figure 4.

Table 3. Full-scale bare hull effective power comparisons, AxWJ vs. MxWJ, no skegs

	Design (DES)			Heavy (HVY)			Light (LITE)		
	AxWJ	MxWJ	AxWJ	AxWJ	MxWJ	AxWJ	AxWJ	MxWJ	AxWJ
Vs (kts)	PE (hp)	PE (hp)	ΔPE (%)	PE (hp)	PE (hp)	ΔPE (%)	PE (hp)	PE (hp)	ΔPE (%)
15	6558	7409	-11.5%	6631	8024	-17.4%	6153	7079	-13.1%
20	15064	17725	-15.0%	15969	22059	-27.6%	14119	16227	-13.0%
25	29492	35158	-16.1%	33237	41695	-20.3%	25511	29625	-13.9%
30	47306	54517	-13.2%	54686	64891	-15.7%	41929	46085	-9.0%
36	85242	92709	-8.1%	95107	113855	-16.5%	76820	80323	-4.4%
39	127665	134824	-5.3%	143358	159095	-9.9%	115258	118399	-2.7%
42	191065	195586	-2.3%	214247	223870	-4.3%	172221	173672	-0.8%

A decrease in bare hull PE, at equivalent displacement, was exhibited for the AxWJ in comparison to the MxWJ as a result of the reduced volume and depth of transom. In the lower half of the speed range, the reduction in resistance was of a greater magnitude than at the higher speeds. Increasing displacement appeared to magnify the transom effect on resistance, especially at low speed. Near the top speed tested, 45 knots, which is currently above the foreseeable speed range of the JHSS hull platform, the larger volume transom of the MxWJ hull exhibited trends towards effective powers lower than that of the smaller volume AxWJ.

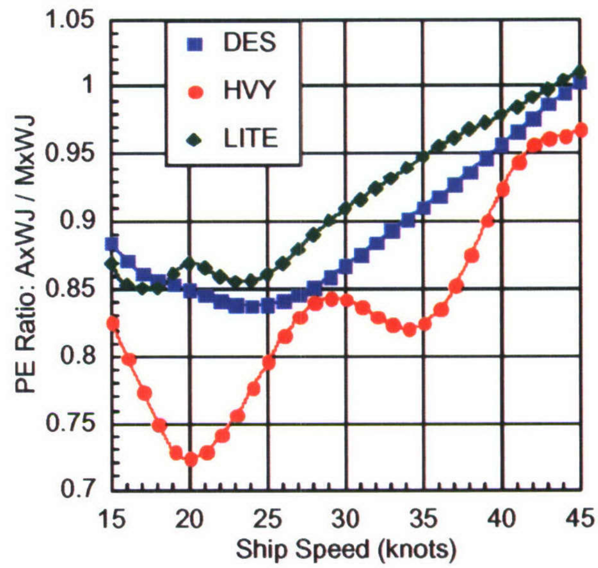

Fig 4. Full-scale bare hull PE comparisons, AxWJ vs. MxWJ

Appended resistance tests, with propulsion nozzles installed, but with the waterjet inlets remaining covered, were conducted on both the AxWJ and the MxWJ, at design displacement. Full-scale appended effective power (PE) predictions, with propulsion nozzles installed, are presented and compared to bare hull for the AxWJ in Tables A7-A8 and Figure A7, and for the MxWJ in Tables B7-B8 and Figure B7. Comparisons between the bare hull and appended PE predictions are presented in Appendix C, Figure C4 and Tables C3-C4. For both the AxWJ and the MxWJ, the propulsion nozzles affected an average resistance increase of less than 1% across the tested speed range of 15 to 45 knots.

Rotor Forces, Over and Under-Propulsion

Powering tests were conducted on both the AxWJ and the MxWJ models at seven powering test speeds of 15, 20, 25, 30, 36, 39, and 42 knots (equivalent full-scale). Model scale rotor force measurements of thrust, torque and RPM were collected for both the AxWJ and the MxWJ, after the models had attained a steady state sinkage and trim, and rotor RPM was adjusted manually to approximately attain the calculated model drag force (F_D) to emulate the ship propulsion point.

Additional test runs were then conducted for over- and under-propelled conditions, at each tested speed. The model rotor RPM was adjusted to nominal ±5% of the RPM values determined for the ship propulsion point. Rotor RPM increases above the value at ship propulsion point is defined as over-propulsion (reduced F_D), and conversely, RPM below ship propulsion point is defined as under-propulsion (increased F_D). The model rotor force measurements, at nominally the ship propulsion point, and in the over- and under-propelled conditions, as tested, are presented in Figure A8 and Table A9 for AxWJ Model 5662, and are presented in Figure B8 and Table B9 for the MxWJ Model 5662-1.

During the testing, model drag force (F_D) was calculated according to the traditional formula, using the ITTC ship and model friction coefficients, correlation allowance, wetted surface corresponding to the bare hull condition, and no form factor. Due to the aforementioned discrepancy in the pre-test calculations of wetted surfaces, the values of F_D to which the models were adjusted during this series of testing were biased high. However, since the over- and under-propelled conditions were also tested concurrently, the data set contains sufficient measurements for the determination of all rotor forces at the equivalent post-test corrected F_D values.

Rotor Forces, Ship Propulsion Point

The rotor force measurements recorded during the over/under propulsion conditions were utilized to determine the powering data at the corrected ship propulsion points (correct F_D values) for both the AxWJ and the MxWJ. AxWJ Model 5662 powering test model-scale rotor force measurements, at ship propulsion point, are presented in Appendix A, Figure A9 and Table A10. Likewise, the powering data for the MxWJ Model 5662-1 are presented in Appendix B, Figure B9 and Table B10.

The rotor force measurements determined during model-scale powering tests are reflective of the model scale pump efficiencies. Direct extrapolation of these rotor forces will not be representative of the expected power requirements of the full-scale waterjets. Full-scale pump efficiencies have been determined to be significantly higher than those measured at model scale. Powering analysis for waterjets requires a significant scope of additional testing and analysis to define mass flow and pressures within the waterjet system. This subsequent testing on both the AxWJ and MxWJ models, continued analysis, and full-scale predictions of waterjet powering on both waterjet hulls, will be reported in subsequent documents.

A comparison between the appended resistance (with propulsion nozzles installed) and powering of the AxWJ and MxWJ, based solely on the model-scale force measurements at the ship propulsion point, is presented in Appendix C, Figure C5 and Table C5, and summarized in Table 4 and depicted in Figure 5. Model-scale PE is calculated from model speed, V_M, and resistance, R_T, and model-scale PD is calculated from model rotor torque, Q_M, and RPM_M.

Table 4. Model-scale powering summary, AxWJ vs. MxWJ, with propulsion nozzles, no skegs

Model-Scale Forces at Ship Propulsion Point										
	MxWJ Model 5662-1				AxWJ Model 5662				AxWJ vs. MxWJ	
VS (kts)	PE (hp)	PD (hP)	PC (ηD)	Rotor (RPM)	PE (hp)	PD (hP)	PC (ηD)	Rotor (RPM)	PE (Δ hP)	PD (Δ hP)
15	0.049	0.063	0.779	942.0	0.045	0.060	0.762	887.0	-7.5%	-5.4%
20	0.115	0.159	0.721	1258.0	0.103	0.159	0.650	1191.5	-10.0%	-0.2%
25	0.222	0.305	0.729	1535.0	0.198	0.296	0.668	1460.0	-10.9%	-2.7%
30	0.353	0.461	0.766	1755.0	0.322	0.451	0.715	1681.8	-8.8%	-2.2%
36	0.596	0.773	0.771	2074.8	0.563	0.780	0.722	2035.3	-5.5%	+0.9%
39	0.825	1.134	0.727	2358.8	0.793	1.210	0.655	2358.8	-3.9%	+6.7%
42	1.139	1.691	0.674	2679.3	1.118	1.834	0.609	2713.8	-1.9%	+8.5%

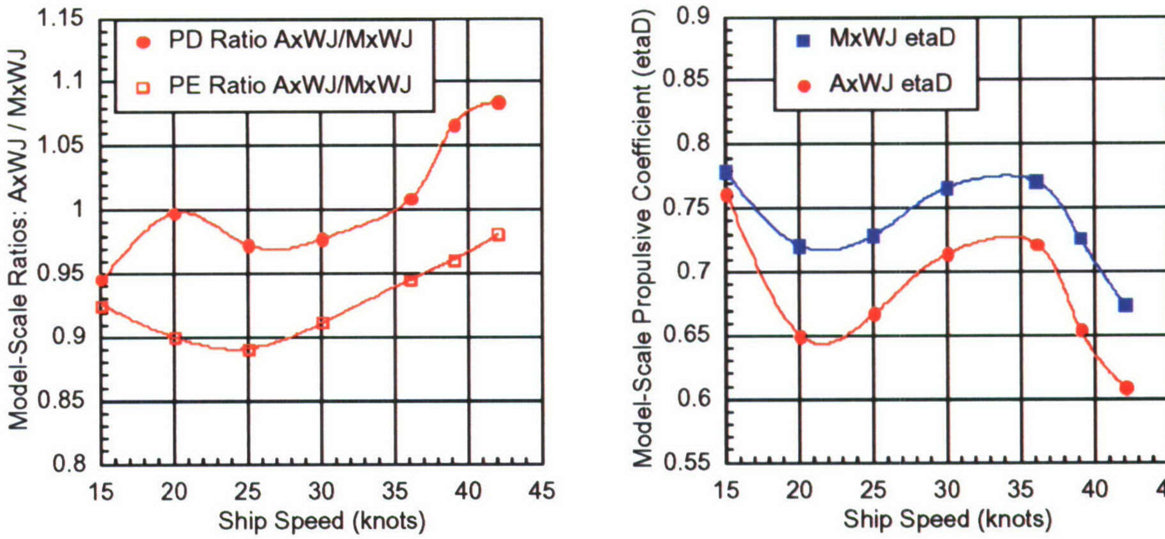

Fig 5. Model-scale resistance and powering comparisons, AxWJ vs. MxWJ

The model-scale comparison of the two waterjet designs shows a decrease in appended model effective power (PE) was exhibited for the AxWJ model in comparison to that of the MxWJ, as exhibited in Figure 5 (o PE Ratio), with the reduction in resistance of a greater magnitude at low speeds relative higher speeds. Model-scale resistance for the AxWJ model overall was 1.9% to 10.9% lower than that of the MxWJ. However, the model-scale powering comparison (λ PD Ratio) shows that the AxWJ has reduced power only up to approximately 35 knots ship speed, with a peak reduction in power of 5.4% at 15 knots. Above that speed the MxWJ model exhibits lower power than that of the AxWJ. At the 39-knot top speed of interest, the MxWJ model exhibits 6.7% lower power.

The comparisons of model-scale propulsive coefficients, η_D, defined as effective power divided by delivered power (PE/PD), show that at model-scale there was a substantial decrease in propulsion efficiency exhibited by the AxWJ (λ) model relative to that of the MxWJ (v). The decrease in propulsion efficiency is most likely a reflection of decreased hull efficiency as a result of the reduced spacing between the pump inlets / waterjet intakes of the AxWJ relative to that of the MxWJ design. The pump inlet clearance of the AxWJ, expressed as a percentage of the pump inlet diameter, is approximately half that of the MxWJ, 42% for the AxWJ in comparison to 83% for the MxWJ.

Dynamic Sinkage and Pitch

The dynamic sinkage and pitch of each model was recorded for each tested ship speed, during all of the resistance and powering tests. The dynamic sinkage and pitch of the AxWJ Model 5662, for all three displacements, recorded during the bare hull resistance tests, are presented and compared in Appendix A, Figure A10 and Table A11. Similarly, the bare hull sinkage and pitch for the MxWJ are presented and compared in Appendix B, Figure B10 and Table B11. Dynamic sinkage and pitch recorded during the powering tests, at DES displacement are presented, and compared to the values from the DES bare hull test, in Figure A11 and Table A12 for the AxWJ, and in Figure B11 and Table B12 for the MxWJ.

Presumably due to the suction force of the operating waterjets, the measured dynamic sinkage and pitch, on both the AxWJ and MxWJ models, were significantly different during the powering tests as compared to the bare hull resistance tests. Across the entire tested speed range, 15 to 42 knots, the recorded sinkage at the Aft Perpendicular (AP) was greater when the

waterjets were operational. Consequently, the sinkage at the Forward Perpendicular (FP) was reduced, and the pitch angle was increased.

Sinkage and pitch comparisons between MxWJ and AxWJ, bare hulls, at three displacements, are presented in Appendix C, Figure C6. Both hulls showed very little variation in sinkage and pitch at any displacement. Sinkage and pitch comparisons between MxWJ and AxWJ, when powered, are presented in Appendix C, Figure C7. Up to a ship speed of about 32 knots, both hulls exhibit similar sinkage and pitch. Above 32 knots, the AxWJ exhibits a greater sinkage at the AP and consequently, a greater pitch angle, although neither is substantially different than that of the MxWJ.

Model Test Uncertainties (Resistance & Rotor Forces)

Measurement uncertainties were determined on AxWJ Model 5662 for the quantities of model speed, and hull resistance, and for combined inboard and outboard shafts quantities of shaft thrust, torque, and rotational speed (RPM), presented in Appendix A, Table A13. Overall uncertainties were determined by combining bias and precision limits using the root-sum-square (RSS) method for a 95 percent confidence level. The values for torque and RPM were then used to determine the uncertainty in the calculation of delivered power. The determined uncertainties for measured model delivered power reflect the combined measurement uncertainties of eight model quantities, shaft torque and RPM, for each of four shafts. Time constraints of the testing series on the MxWJ Model 5662-1 did not allow for a similar determination of measurement uncertainties on this model. However, due to the similarity of the two hulls, and the use of the identical rotors, measurement instrumentation, electronics, and testing techniques, it can be assumed that the measurement uncertainty between the two hulls would be similar.

Resistance measurement uncertainties, at 25 and 36 knots, were determined to be $\pm$0.85% and $\pm$0.33% of the measured nominal mean values, respectively. AxWJ model-scale resistance reduction was in the range of 1.9% to 10.9% lower than that of the MxWJ. Likewise, the model scale delivered power measurement uncertainties were $\pm$1.72% and $\pm$1.05%, at 25 and 36 knots. AxWJ model exhibited a reduction in power of 5.4% at 15 knots ship speed, varying up to a peak increase in power of 8.5% at 42 knots.

COMPARISONS OF WATERJET VARIANTS TO JHSS BASELINE HULL

Comparisons between the AxWJ (Model 5662) and MxWJ (Model 5662-1) waterjet propulsion variants, and the JHSS Baseline Shaft & Struts (BSS) parent hull platform (Model 5653), are presented in Appendix C.

A comparison of the bare hull PE values of the two waterjet variants, AxWJ and MxWJ, at the three displacements, to that of the bare hull JHSS baseline BSS, is presented in Appendix C, Figure C3 and Table C2, and summarized, at design displacement, in Figure 6. The AxWJ at DES, HVY, and LITE displacements, respectively, exhibited a speed-averaged bare hull resistance of 16.4%, 16.6%, and 10.2% higher than that of the bare hull BSS at equivalent displacement. Likewise, the MxWJ exhibited bare hull resistance of 30.9%, 40.8%, and 21% higher than that of the BSS. These substantial increases in bare hull resistance for the waterjet variants over that of the BSS are a result of the greater volume and depth of transom in these designs, required to house the waterjets. The MxWJ, with the greatest transom volume, exhibits the highest bare hull resistance throughout the entire foreseeable JHSS speed range. Again, transom depth was dictated primarily by the criterion, that, in order to assure rotor priming, half of the waterjet inlet diameter should remain submerged at design displacement. A relaxation of this criterion would likely reduce the bare hull resistance of both waterjet variants.

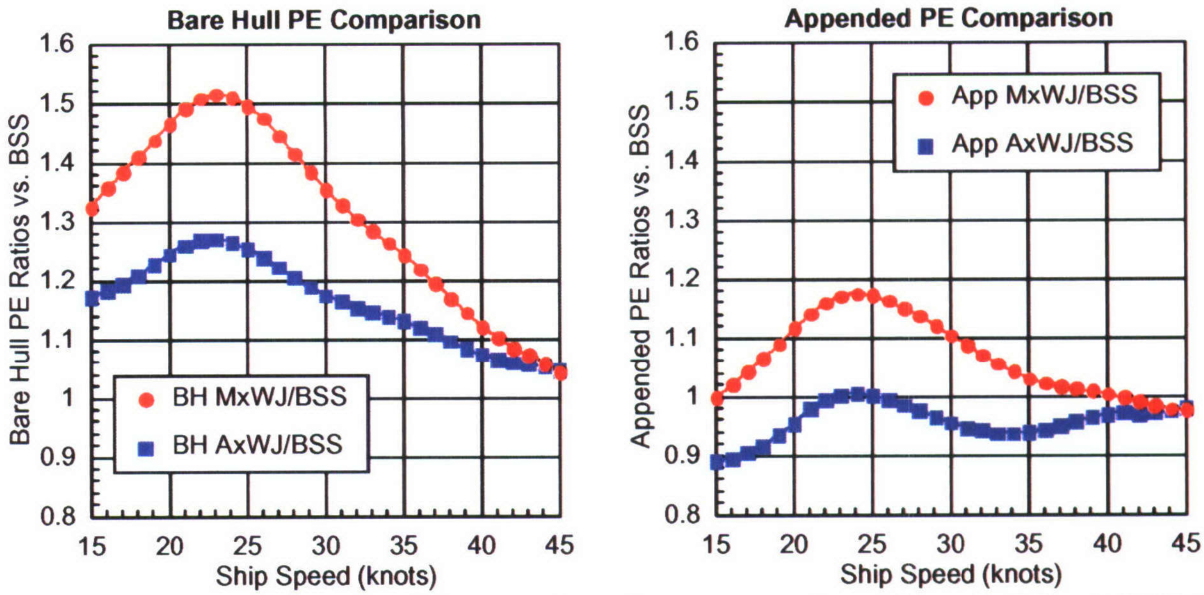

Fig 6. Bare hull and appended PE comparisons between waterjet variants AxWJ and MxWJ versus JHSS baseline BSS, at design displacement

The present AxWJ and MxWJ tests were conducted on models without the installation of a centerline skeg. It is the opinion of the HWG that the full-scale waterjet hulls would likely require a centerline skeg for structural support during construction and dry-docking, and for directional stability. In order to compare the expected appended resistances for the AxWJ and MxWJ variants to the appended resistance of the JHSS baseline BSS, the resistance of a centerline skeg must be added to the effective power predictions presented with the propulsion nozzles installed. An estimate of the added effective power, due to the installation of a centerline skeg on the AxWJ, was prepared by H. Liu (Code 5200), based upon his previous appendage drag evaluation.[5] The skeg design utilized was that previously included on the AxWJ hull. This skeg increased the hull wetted surface by 6667ft^2 (6.5% increase). The skeg added effective power was then applied to the resistance predictions with propulsion nozzles, for both the AxWJ and MxWJ.

The appended PEs of the AxWJ and MxWJ (with propulsion nozzles installed and estimated skeg drag added), were compared to that of the JHSS baseline BSS hull, fully appended (skeg, shafts & struts, rudders, and stern flap), at DES displacement [Ref 6], and are presented in Appendix C, Figure C4 and Table C3, and included in Figure 6. Throughout almost all of the speed range, the AxWJ, at design displacement, exhibits an appended effective power lower than that of the fully appended BSS. Across the speed range, the appended AxWJ averaged 4.4% lower PE than that of the BSS. For the MxWJ, at all but the highest speeds, the appended PE was higher than that of the BSS, averaging 6.5% higher. This comparison between the two sets of data comprising Figure 6, plotted on equivalent axis for clarity, indicates that even though the waterjet hulls are at a great disadvantage in bare hull resistance when compared to that of the BSS, the requirement of additional appendages on the BSS hull for propulsion (i.e. shafts, struts, rudders) increases that hull's appended resistance to a value greater than the AxWJ hull and only slightly lower than that of the MxWJ hull.

Direct extrapolation of model-scale rotor force measurements for the waterjet variants will not be representative of the expected power requirements of the full-scale waterjets, due to significant differences in model vs. full-scale pump efficiencies. Therefore, additional analysis

[5] NSWCCD report of limited distribution

is required to determine the full-scale propulsion for the AxWJ and MxWJ variants before they can be adequately compared to that of the JHSS baseline BSS.

CONTINUATION OF WORK

A significant scope of each test series, on the AxWJ Model 5662 and MxWJ Model 5662-1, was dedicated to the waterjet flow surveys conducted with the Laser Doppler Velocimetry (LDV) system, under the direction of D. Fry (Code 5400), and to the measurement of pressures within the waterjet system, under the direction of M. Donnelly (Code 5400). Detailed explanations of the LDV and the pressure measurement systems, recorded data, subsequent analysis, and ultimately full-scale predictions of waterjet powering on these JHSS waterjet hulls, will be reported in subsequent documentation.

RECOMMENDATIONS

Comparisons of model-scale propulsive coefficients, η_D, show that at model-scale there was a substantial decrease in propulsion efficiency exhibited by the AxWJ model relative to that of the MxWJ, even though the identical surrogate model pumps were utilized. The decrease in propulsion efficiency is most likely a reflection of decreased hull efficiency as a result of the reduced spacing between the pump inlets / waterjet intakes of the AxWJ relative to that of the MxWJ design. The pump inlet clearance of the AxWJ is approximately half that of the MxWJ.

It is recommended that a third waterjet variant be designed to evaluate the effect of waterjet inlet spacing on propulsive coefficient. The third variant should retain the current AxWJ full-scale design criteria for waterjet size and waterjet inlet draft (submergence), but with a waterjet inlet spacing equivalent to that of the MxWJ. This set of criteria would produce a waterjet stern with equivalent width of the MxWJ, but maintaining the much shallower draft of the AxWJ. Numerical studies and model tests should be conducted to determine if the performance of this third variant could maintain a somewhat reduced effective power of the AxWJ relative to MxWJ, but retain a higher propulsive coefficient similar to that of the MxWJ. The resultant may be a waterjet variant with a powering performance better than either the current AxWJ or MxWJ.

CONCLUSIONS

This report is the documentation of the model-scale calm water evaluation of the relative performance merits between two different waterjet propulsion variants on the JHSS hull platform, the Axial Waterjet (AxWJ) Model 5662 and the Mixed-Flow Waterjet (MxWJ) Model 5662-1. It is intended to be a record of the hull resistance and model-scale powering data and analysis. Full-scale predictions of waterjet powering, and comparison to the JHSS Baseline Shaft & Strut (BSS) parent hull, after the completion of a significant scope of additional model-scale waterjet testing analysis, will be reported in a subsequent document.

Bare hull effective powers were determined for the AxWJ and MxWJ at three displacement conditions, design (DES) and $\pm$ 10% displacements. A decrease in bare hull PE, at equivalent displacement, was exhibited for the AxWJ in comparison to that of the MxWJ as a result of the reduced volume and depth of transom. In the lower half of the speed range, the reduction in resistance was of a greater magnitude than at the higher speeds. Increasing displacement appeared to magnify the transom effect on resistance.

At all three displacements, both the AxWJ and MxWJ exhibited bare hull resistances significantly higher than that of the bare hull JHSS baseline BSS at equivalent displacement. Increase in bare hull resistance for the waterjet hulls are a result of the greater volume and depth of transom in these designs, required to house the waterjets. The MxWJ, with the greatest transom volume, exhibits the highest bare hull resistance throughout the entire foreseeable JHSS

speed range. Waterjet transom designs were dictated by several criteria, in order to assure rotor priming and adequate space/volume to accommodate the waterjets and equipment. A possible relaxation in these criteria would decrease overall transom sizing, and likely reduce the resistance of the waterjet hulls.

Appended effective powers were determined for the AxWJ and MxWJ (with propulsion nozzles installed and estimated skeg drag added), and compared to that of the fully appended BSS hull (skeg, shafts & struts, rudders, and stern flap). Even though the waterjet hulls are at a great disadvantage in bare hull resistance when compared to that of the BSS, the requirement of additional appendages on the BSS hull for propulsion increases that hull's appended resistance to a value greater than that of the AxWJ hull and only slightly lower than that of the MxWJ hull.

Model-scale rotor force measurements were recorded for the AxWJ and MxWJ models when under power. Due to significant differences in model-scale versus full-scale pump efficiencies, direct extrapolation of rotor forces measured at model-scale will not be representative of the expected power requirements of the full-scale waterjets. A comparison between the powering of the AxWJ and MxWJ, based solely on the model-scale forces at the ship propulsion point, shows that the AxWJ has reduced power only up to approximately 35 knots ship speed. Above that speed the MxWJ model exhibits lower power than that of the AxWJ. Comparisons of model-scale propulsive coefficients, η_D, show that at model-scale there was a substantial decrease in propulsion efficiency exhibited by the AxWJ model relative to that of the MxWJ. The decrease in propulsion efficiency is most likely a reflection of the reduced spacing between the pump inlets / waterjet intakes of the AxWJ relative to that of the MxWJ design. The pump inlet clearance of the AxWJ is approximately half that of the MxWJ.

Additional analysis is required to determine the full-scale propulsion for the AxWJ and MxWJ variants before they can be adequately compared to that of the JHSS baseline BSS.

It is recommended that a third waterjet variant be designed and tested to evaluate the effect of waterjet inlet spacing on propulsive coefficient. This third variant would combine some of the design aspects of both the AxWJ and MxWJ. Numerical studies and model tests should be conducted to determine if the performance could maintain the comparative lower effective power of the AxWJ, as well as retain a higher propulsive coefficient of the MxWJ, and possibly result in a waterjet powering performance better than either.

ACKNOWLEDGEMENTS

NSWWCD Technical Point of Contact (TPOC) for the JHSS waterjet designs, AxWJ and MxWJ, is Stuart Jessup (Code 503). Points of contact for the topics contained within this document are: Dominic S Cusanelli (Code 5200) for the resistance and powering, David Fry (Code 5400) for the LDV surveys, Martin Donnelly (Code 5400) for the pressure measurements, and Anne Marie Powers (6530) for the model laser measurements.

Current members of the High Speed Sealift Hydro Working Group (HWG) include the following individuals. From NSWCCD: Robert Anderson, HWG chairman (Code 2410); Stuart Jessup (503); Gabor Karafiath, Dominic S. Cusanelli, Rae Hurwitz (5200), Scott Black, Michael Wilson, Thad Michael (5400); Andy Silver (5500); Siu Fung, Colen Kennell, and George Lamb (2420); and Edward Devine (6540). Additional HWG members are: Jack Offutt (consultant); Christopher Dicks (FORNATL-UK); and Jeff Bohn, Steve Morris, and John Slager (CSC).

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REFERENCES

1. "Rapid Strategic Lift Ship Feasibility Study Report", Ser 05D/097, NAVSEA 05D, (29 Sept. 2004).
2. Wynn, Steven, "Joint High Speed Sealift (JHSS)", NAVSEA Presentation, (March 8, 2006).
3. Cusanelli, D.S. and S.A. Carpenter, "JHSS Axial Waterjet (AxWJ) Model 5662: Hull Resistance and Model-Scale Powering with LDV Nozzle Design", NSWCCD-50-TR-2007/059 (Sept 2007).
4. Cusanelli, D.S., "Joint High Speed Sealift (JHSS) Baseline Shaft & Strut (Model 5653) Series 1: Bare Hull Resistance, Appended Resistance, and Alternative Bow Evaluations" 50-TR–2007/066 (Aug 2007).
5. Cusanelli and Bradel, "Floating Platform Tow Post" United States Patent No. 5,343,742 (Sept. 6, 1994).
6. Cusanelli, D.S. and C.D. Chesnakas, "Joint High Speed Sealift (JHSS) Baseline Shaft & Strut (BSS) Model 5653: Series 2, Propeller Disk LDV Wake Survey; and Series 3, Stock Propeller Powering and Stern Flap Evaluation Experiments", NSWCCD-TR-2007/084 (Sept 2007).

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Appendix A

Axial Waterjet (AxWJ) Model 5662 Data

APPENDIX A FIGURES

APPENDIX A TABLES

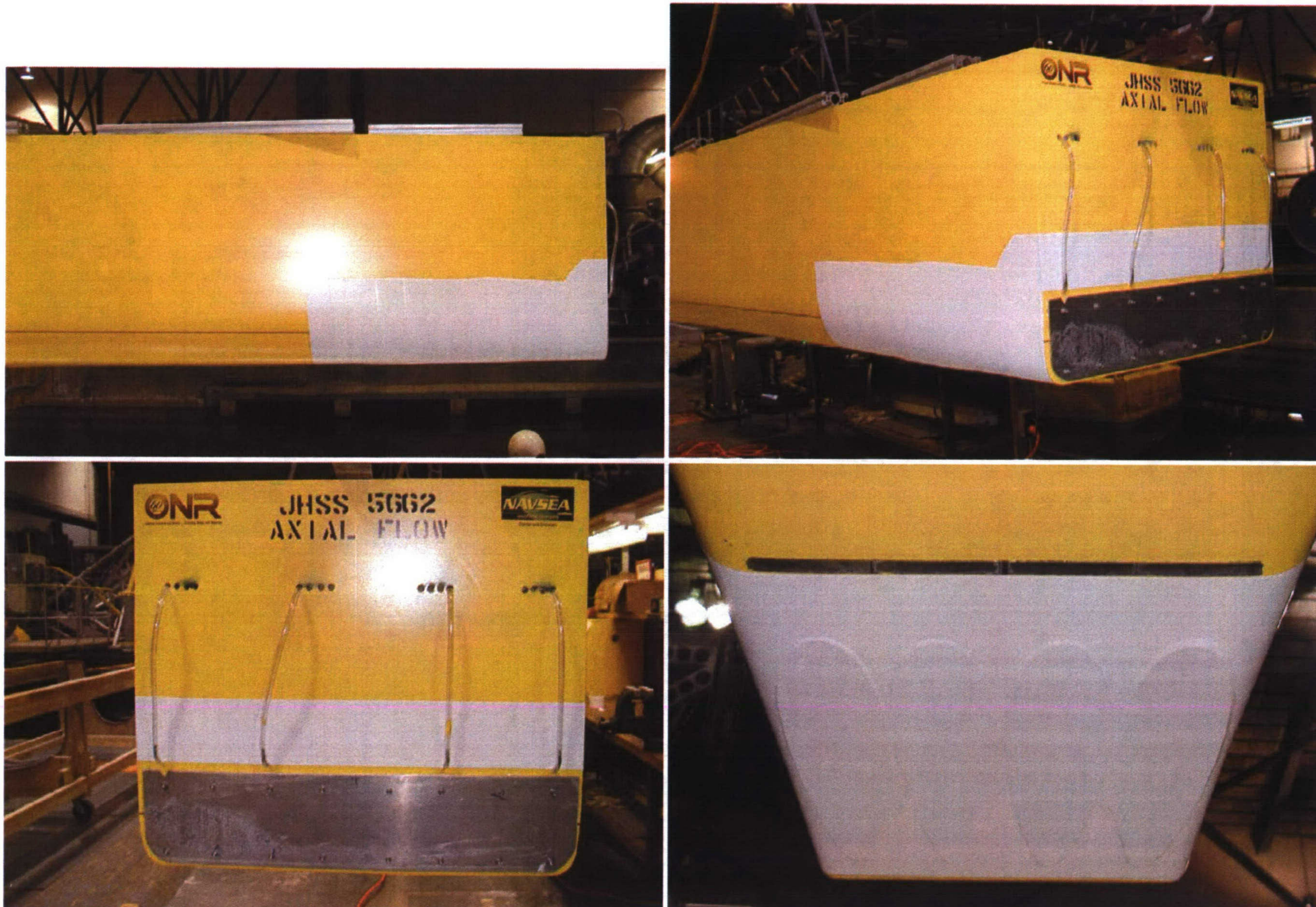


Fig A1. AxWJ Bare Hull (May 2007)

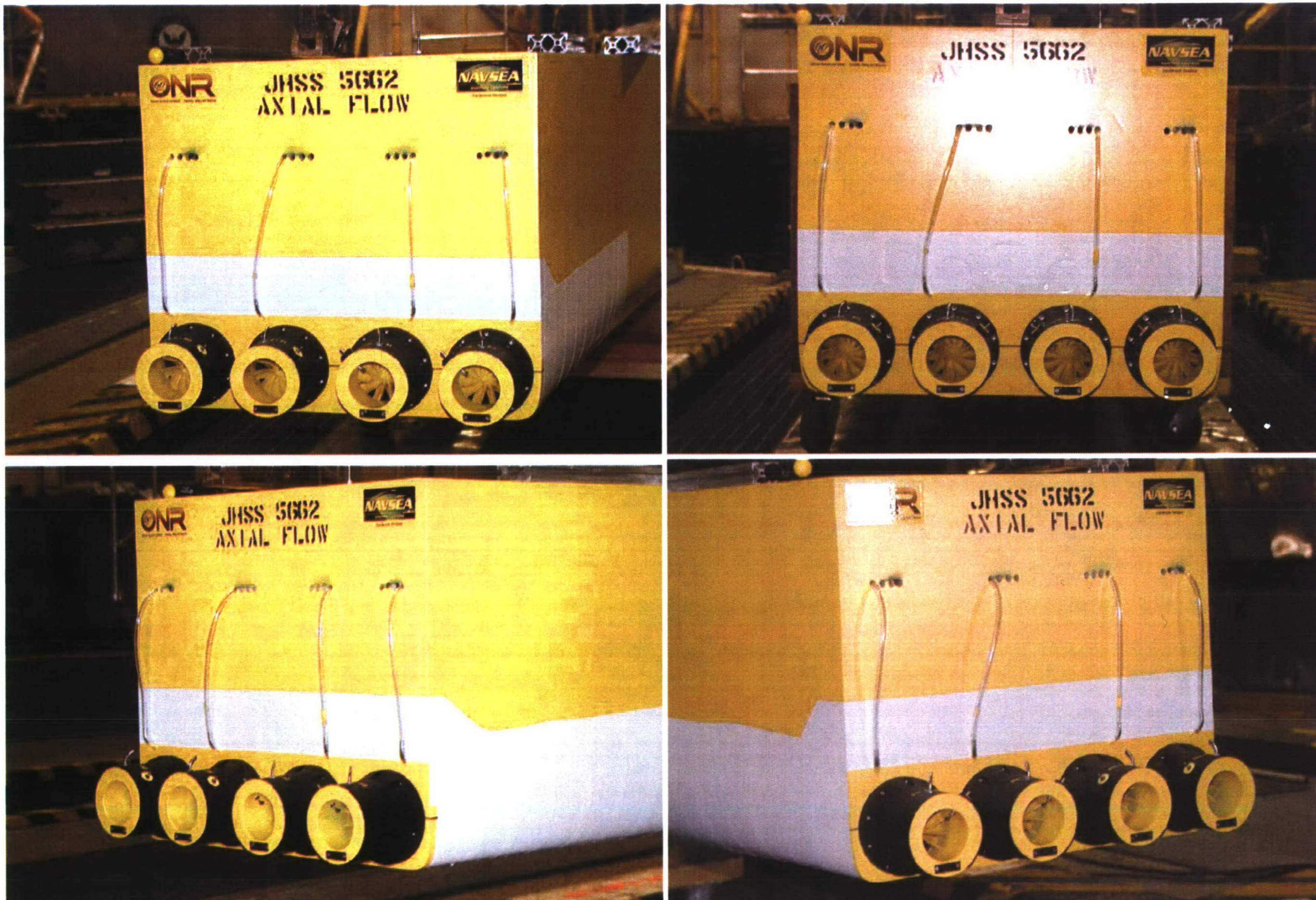


Fig A2. AxWJ with inlets covered, propulsion nozzles installed, (May 2007)

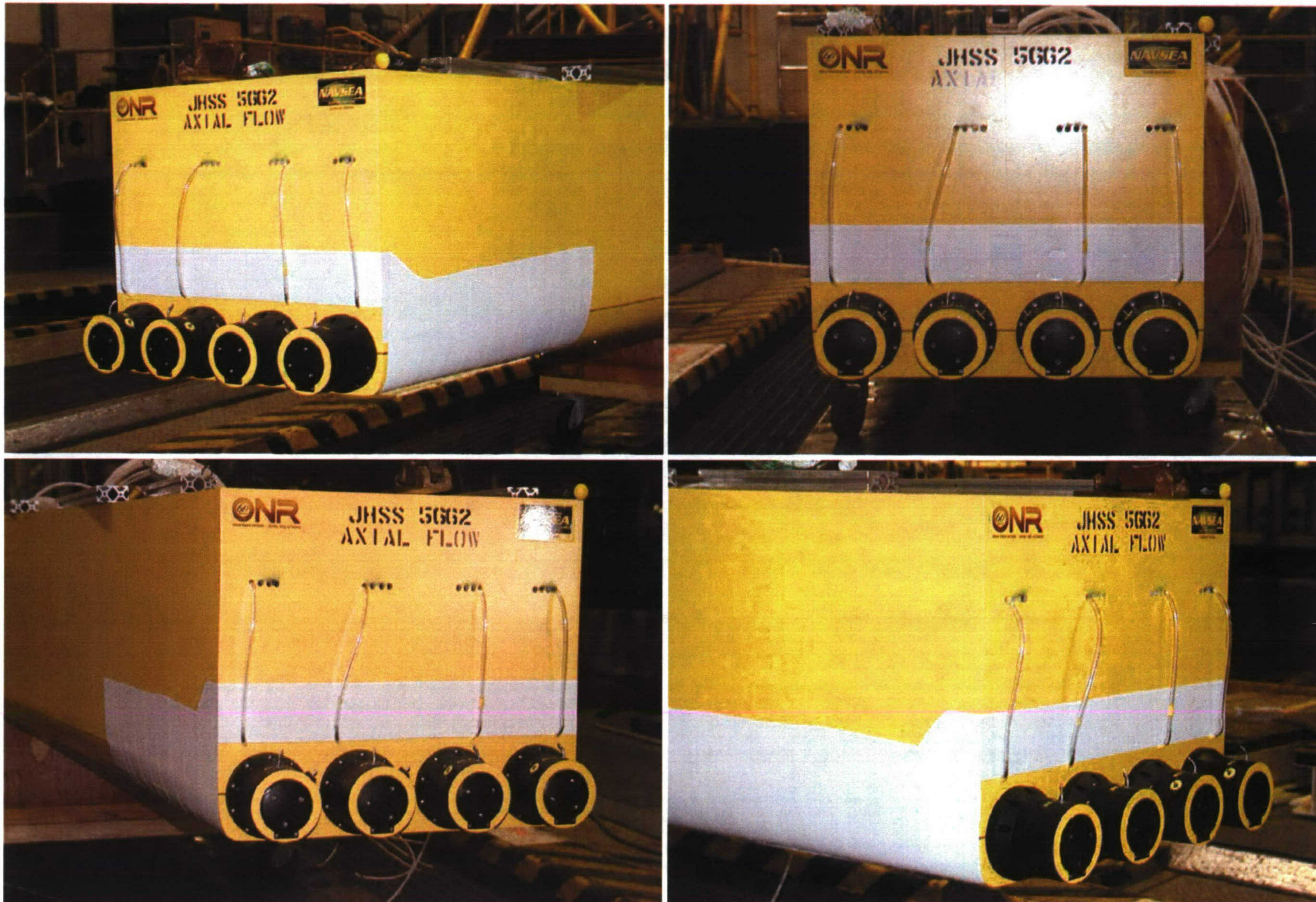


Fig A2. AxWJ with inlets covered, propulsion nozzles installed, (May 2007) - continued

Fig A3. AxWJ propulsion nozzles installed, inlets open (May 2007)

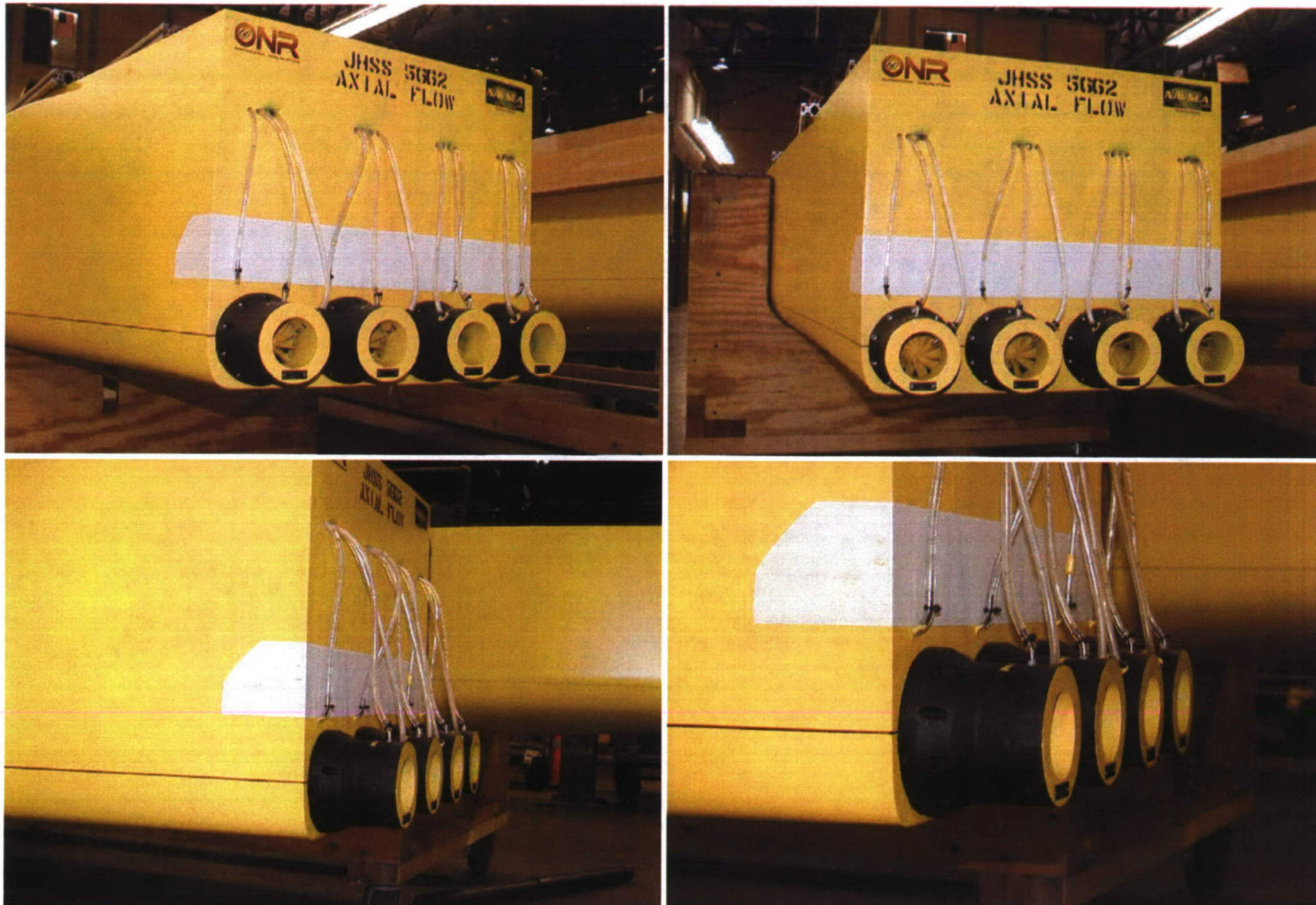


Fig A3. AxWJ propulsion nozzles installed, inlets open (May 2007) - continued

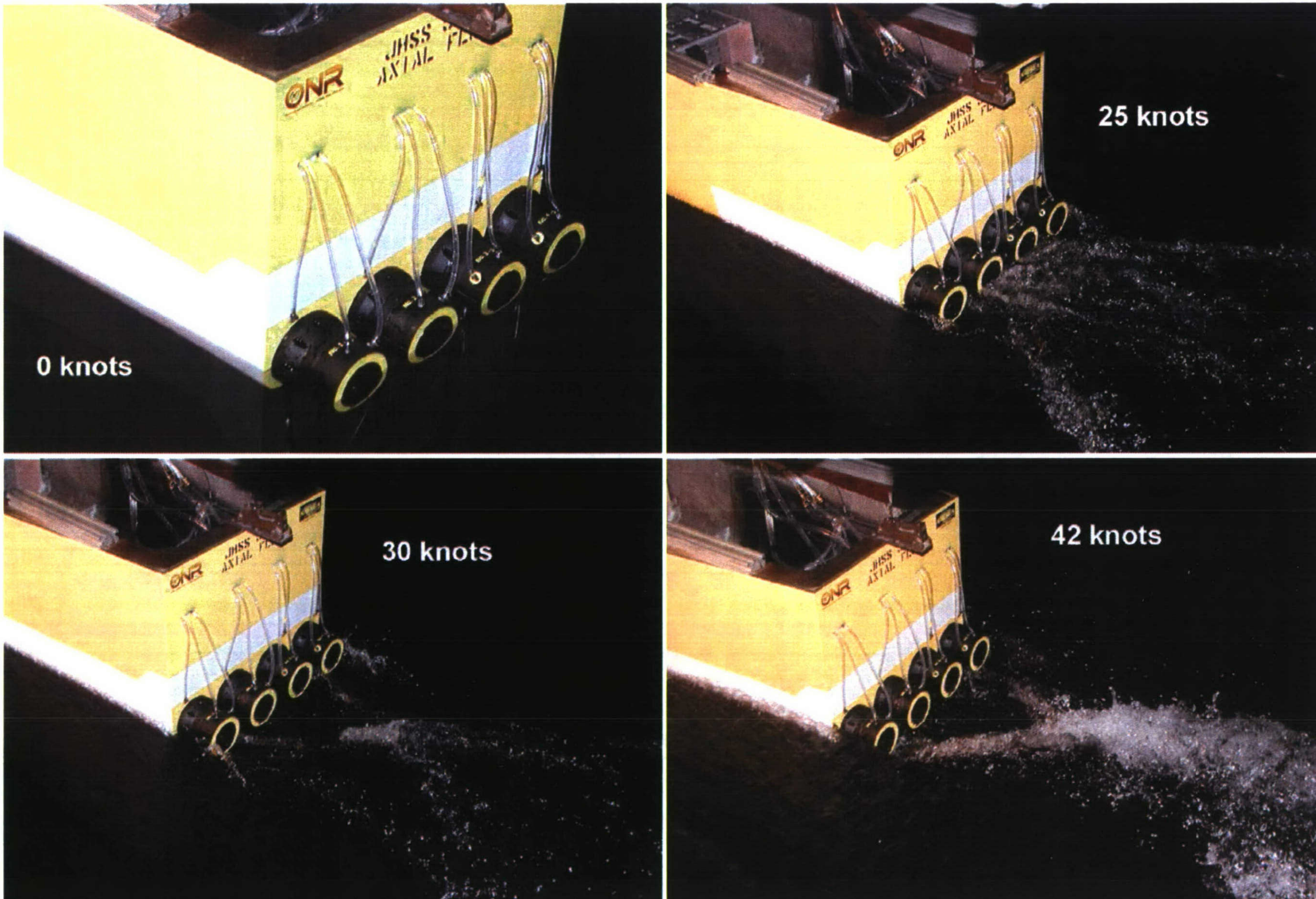


Fig A4. AxWJ resistance test underway (May 2007)

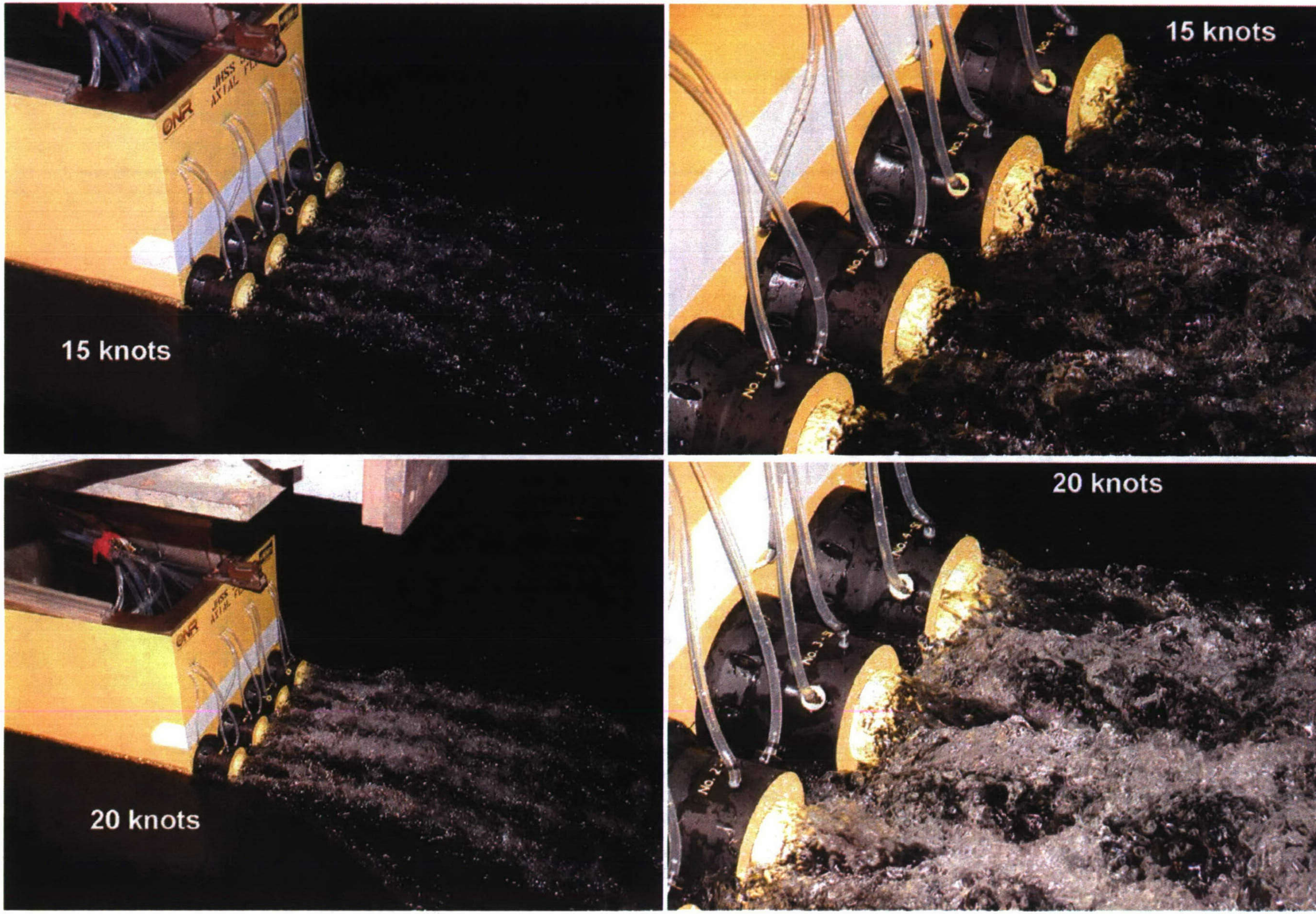


Fig A5. AxWJ powering test underway (May 2007)

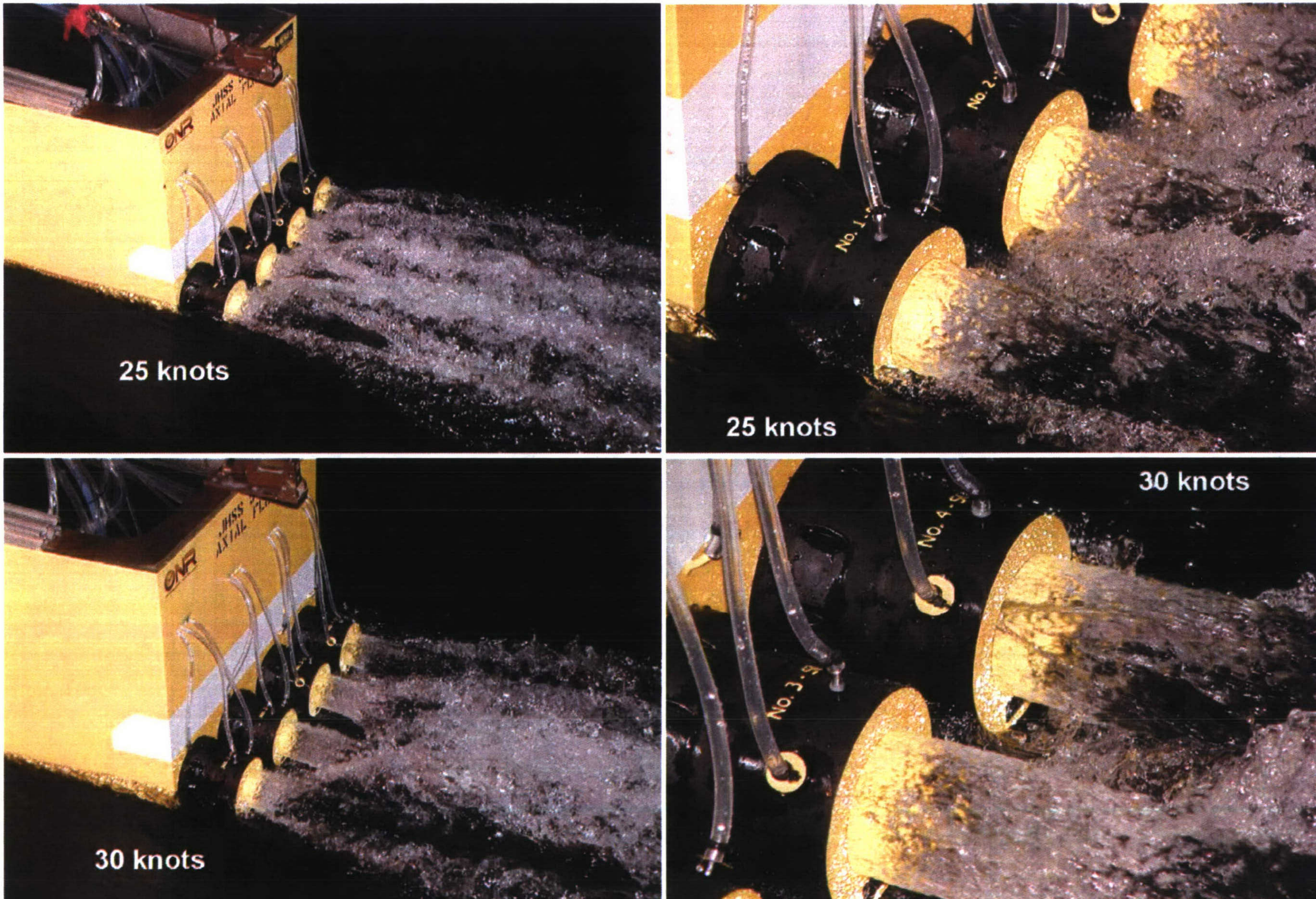


Fig A5. AxWJ powering test underway (May 2007) - continued

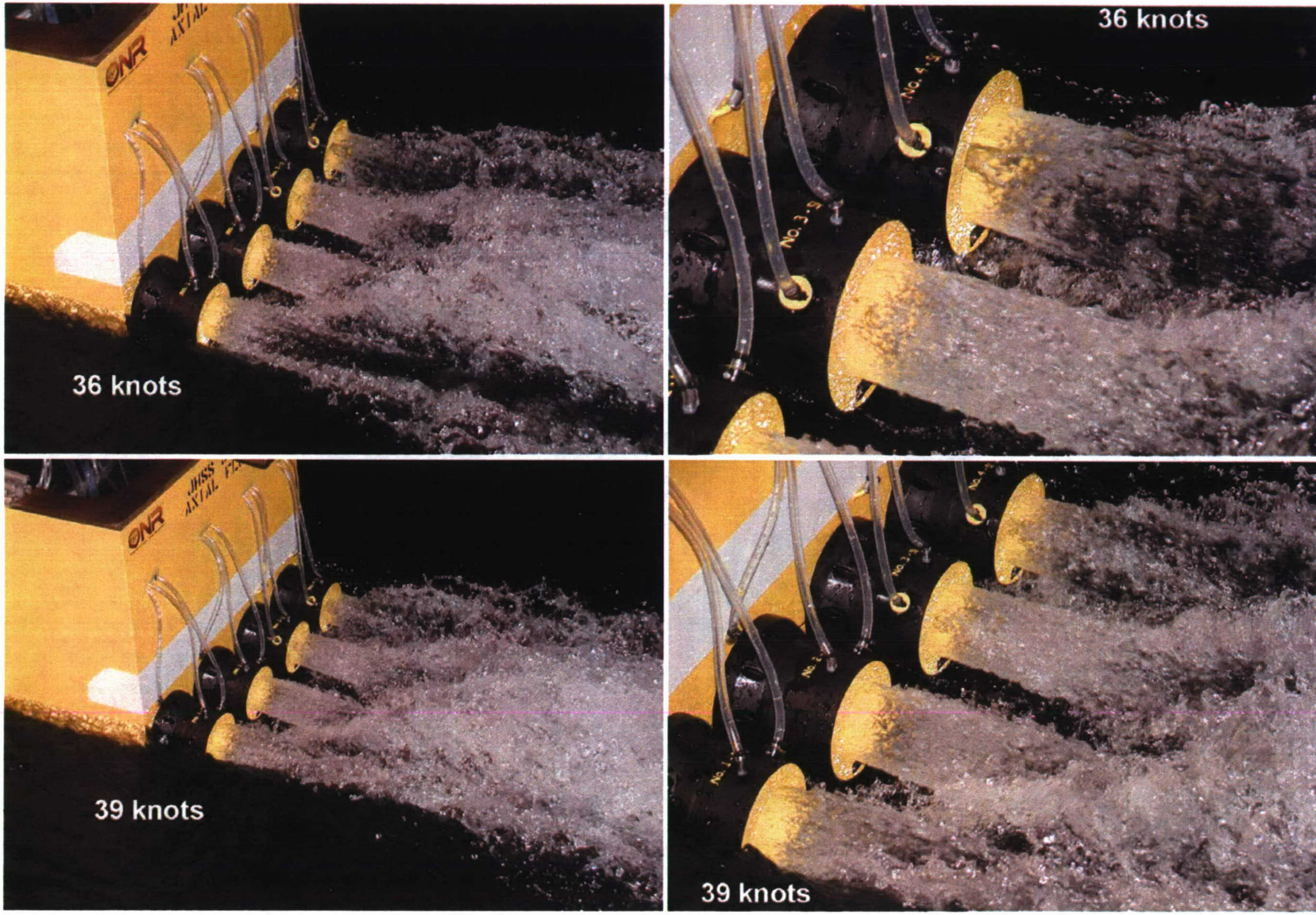


Fig A5. AxWJ powering test underway (May 2007) - continued

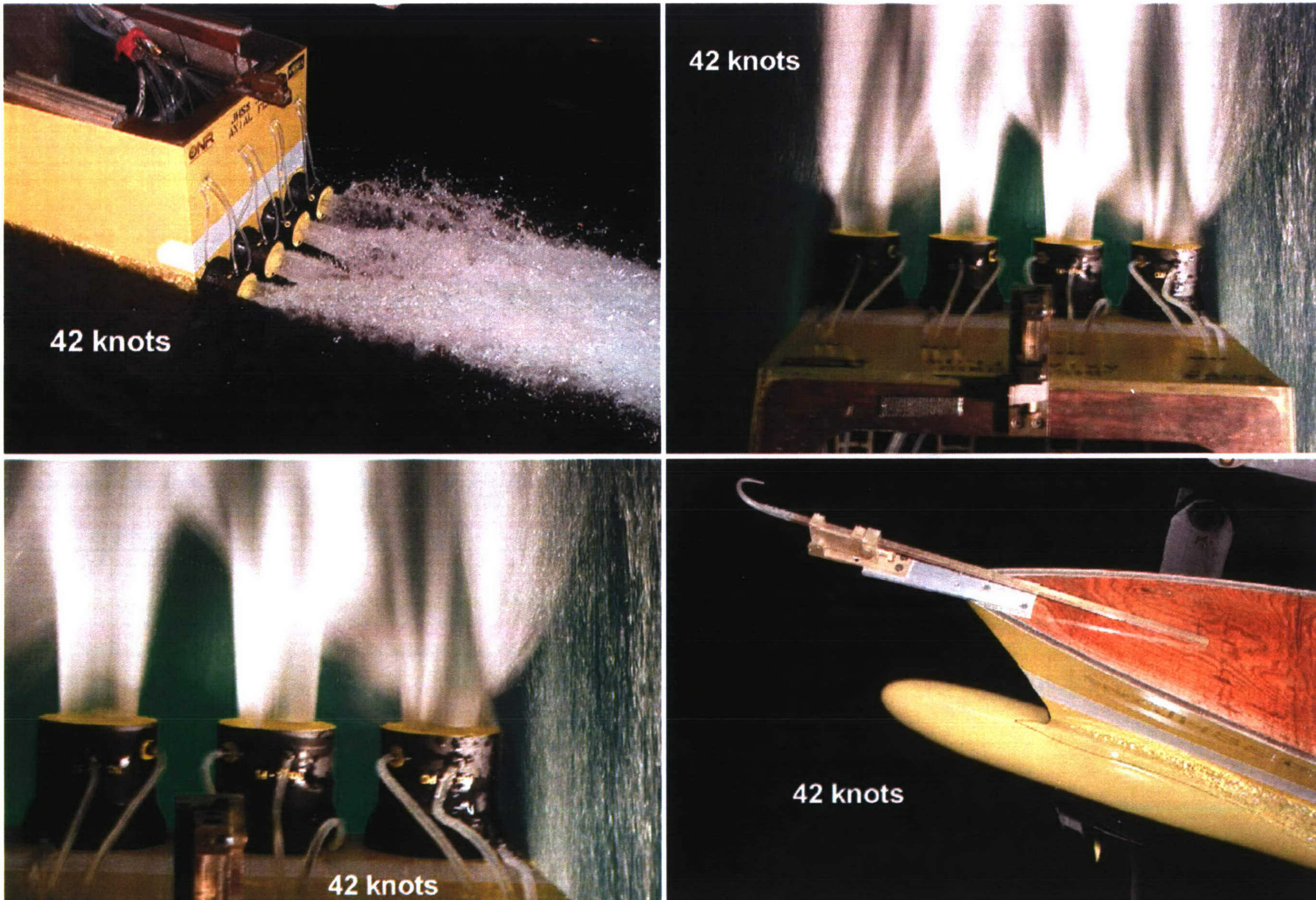


Fig A5. AxWJ powering test underway (May 2007) - continued

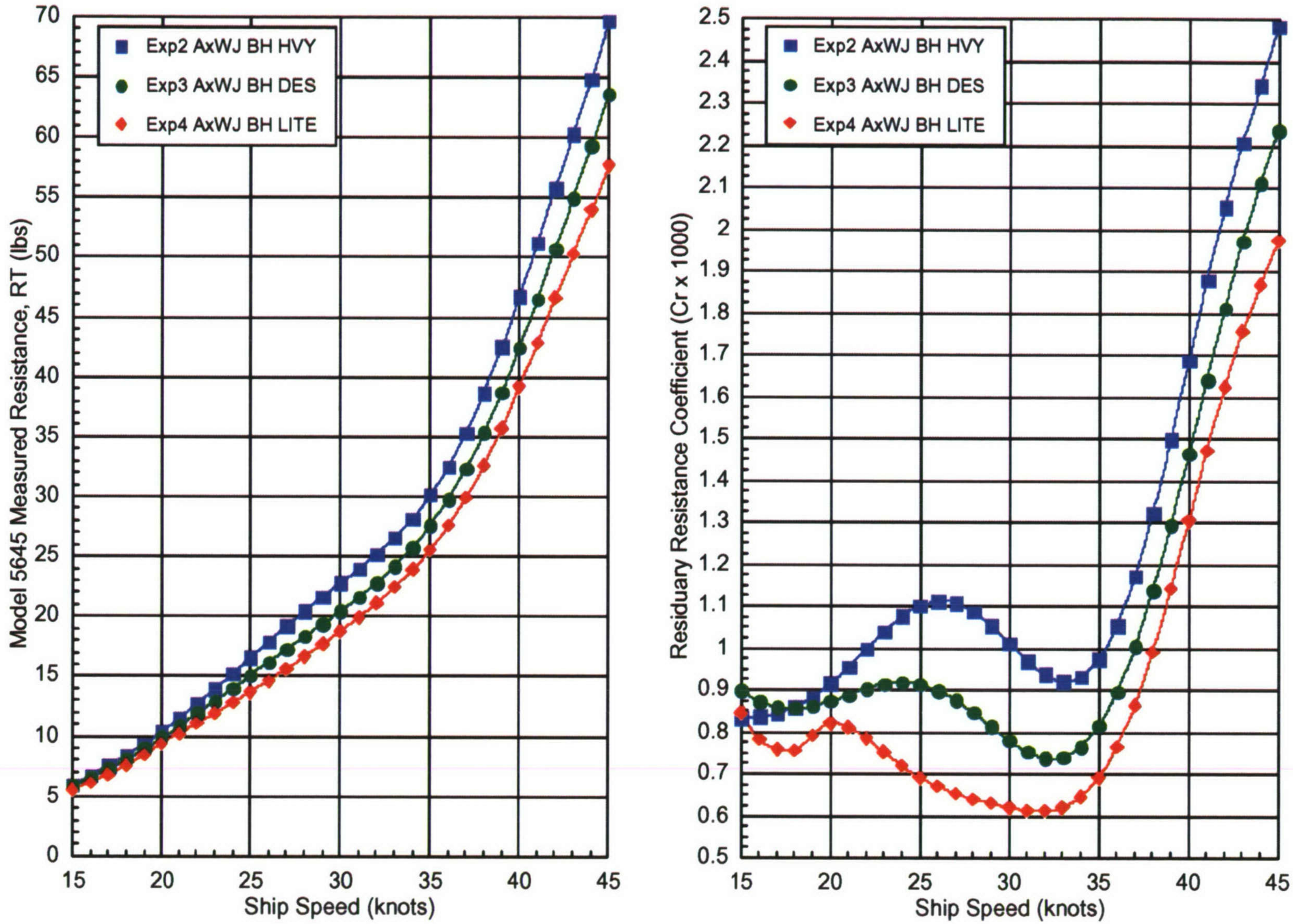
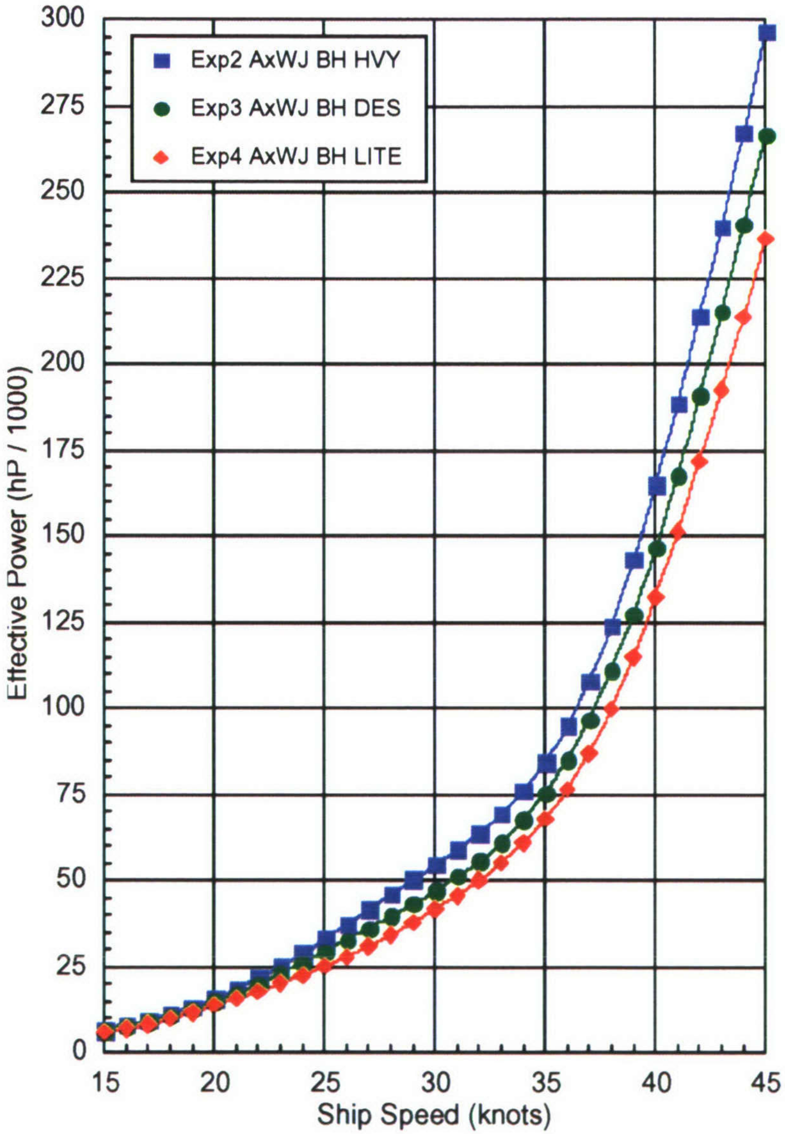


Fig A6. AxWJ, bare hull resistance comparisons at three displacements



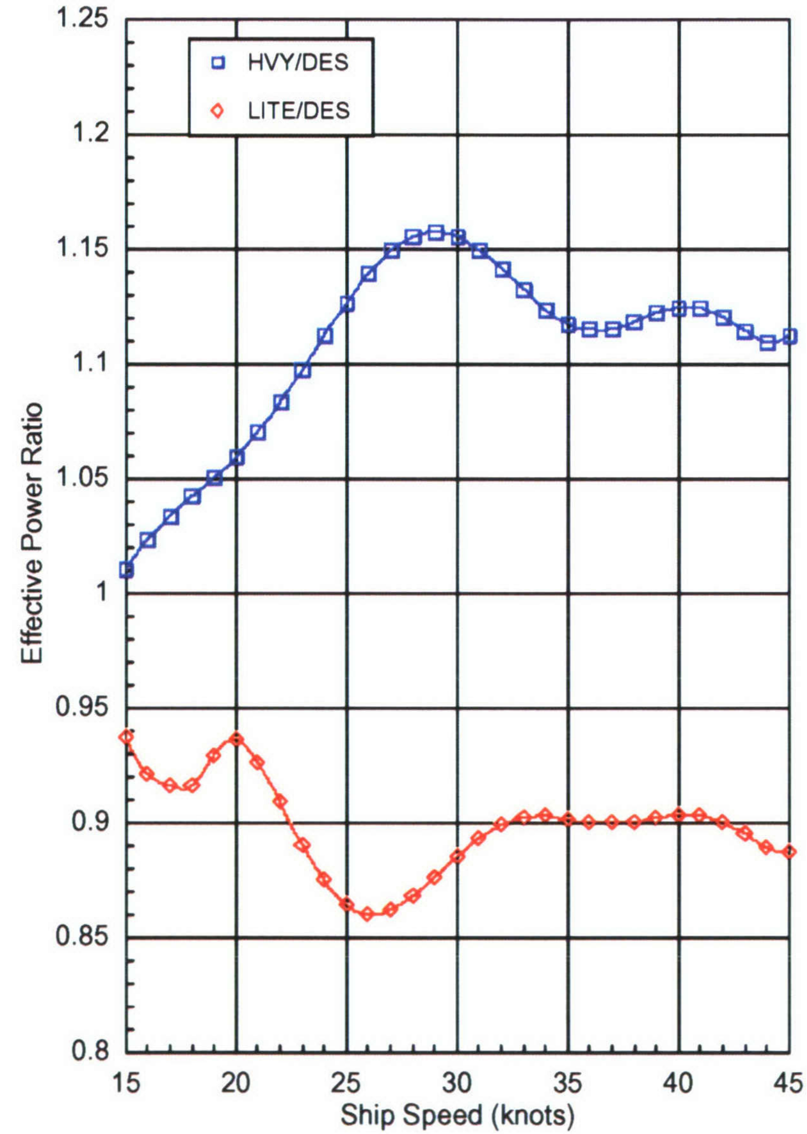


Fig A6. AxWJ, bare hull resistance comparisons at three displacements - continued

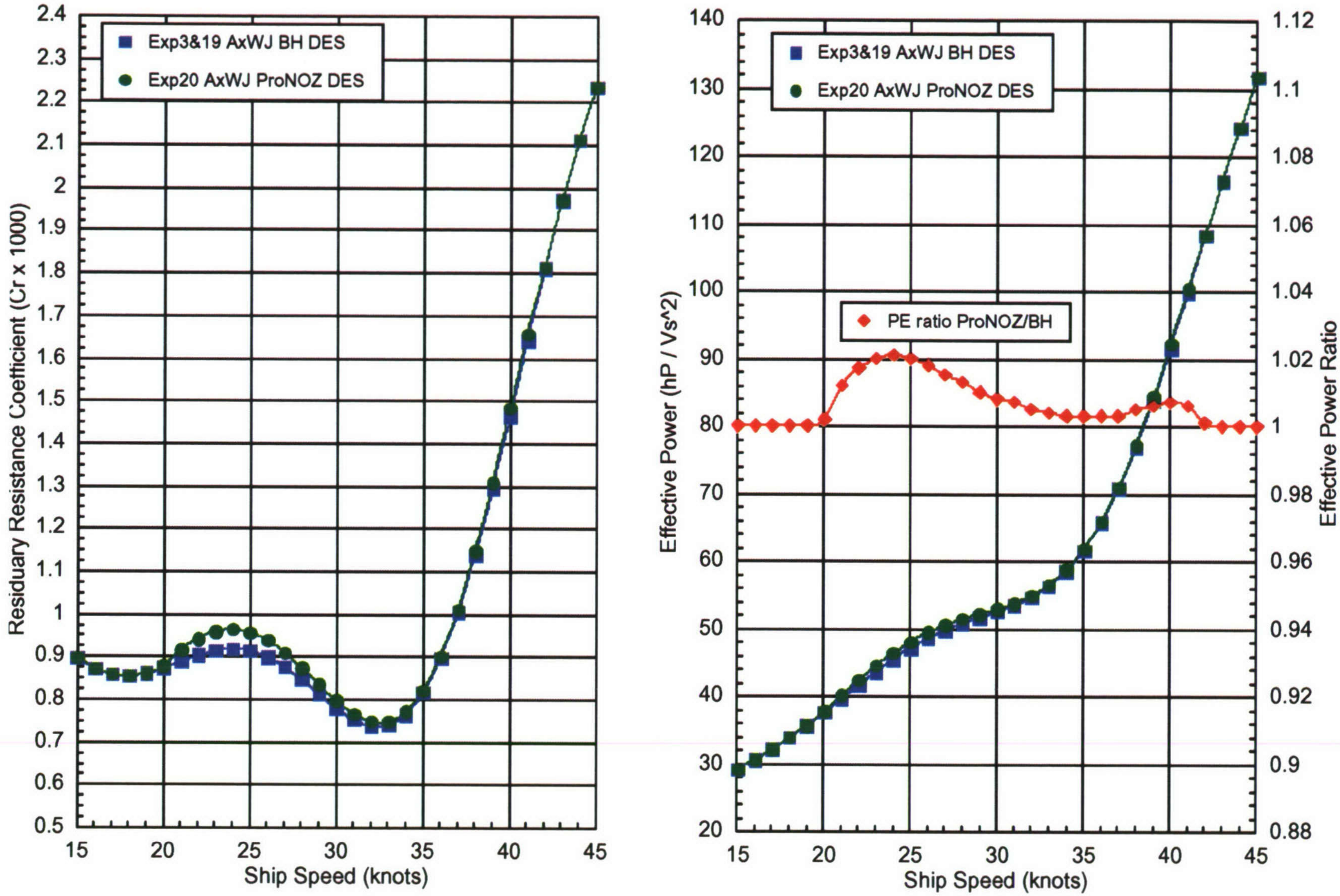


Fig A7. AxWJ resistance comparison, hull with nozzles installed versus bare hull

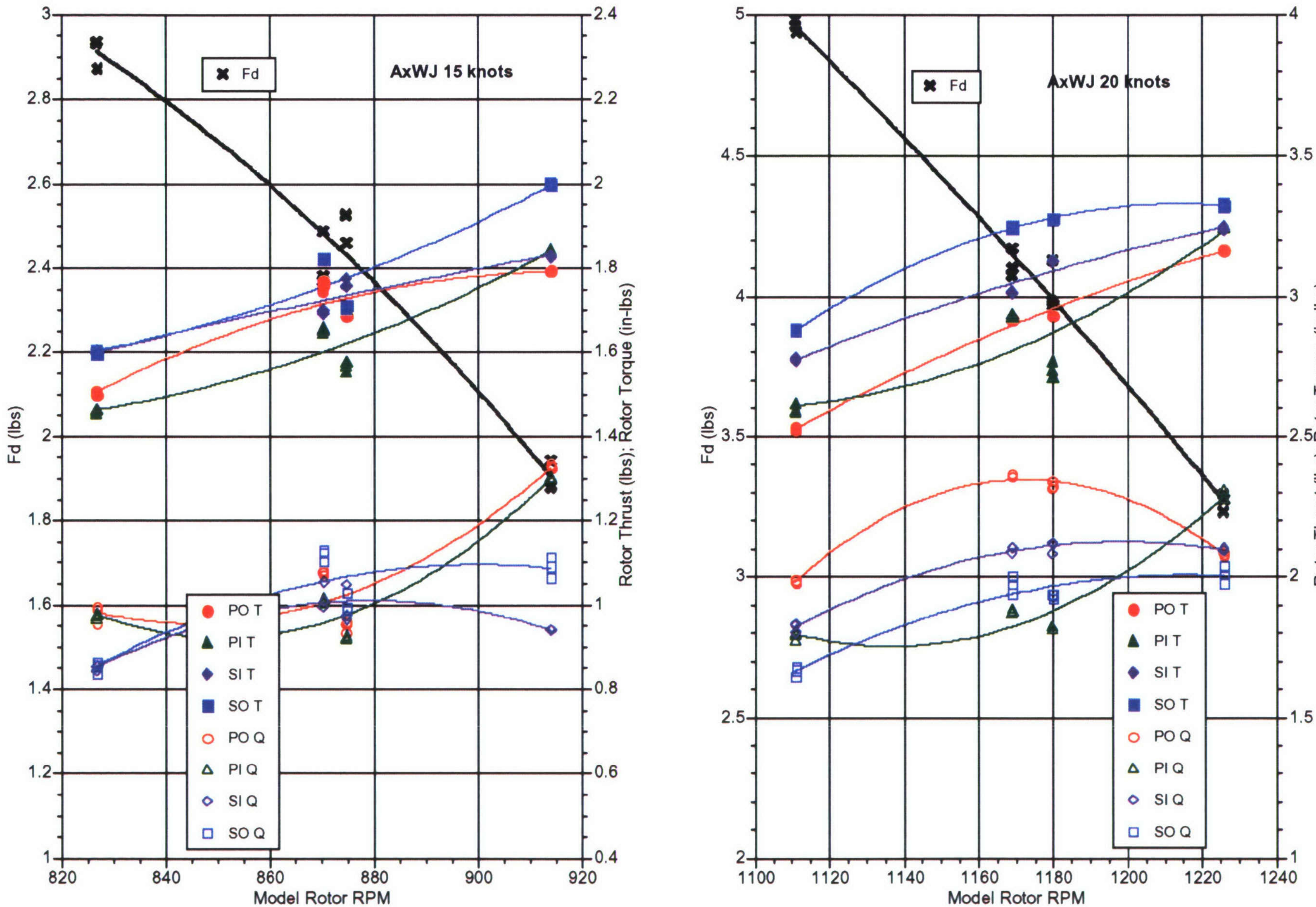
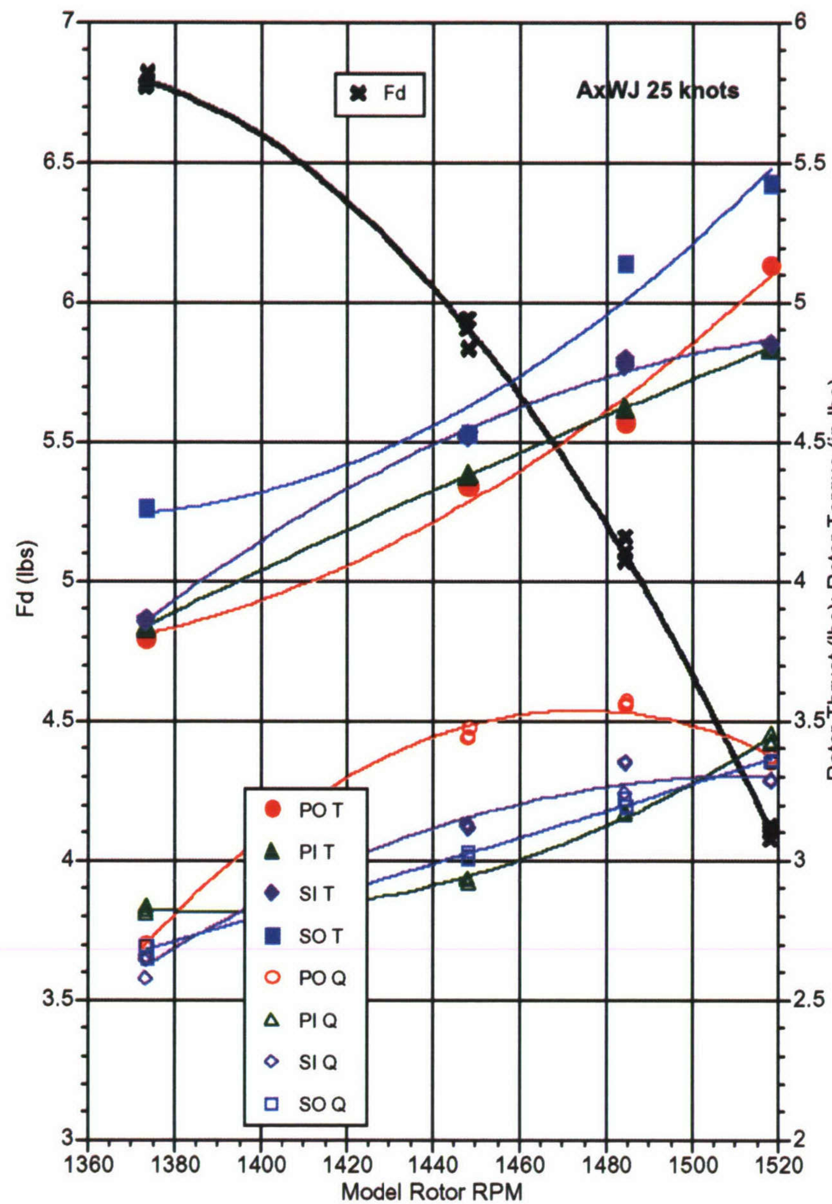


Fig A8. AxWJ over- and under-propelled data, model-scale



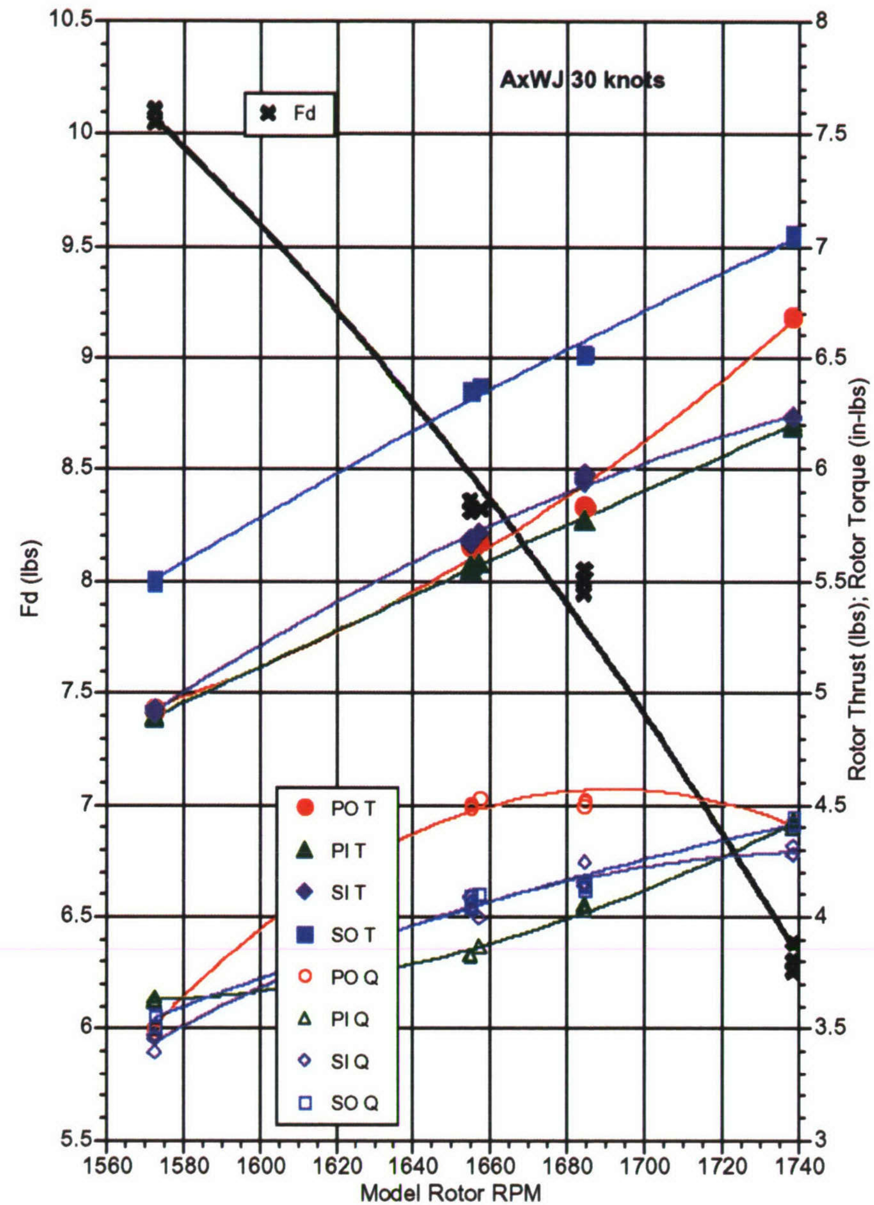
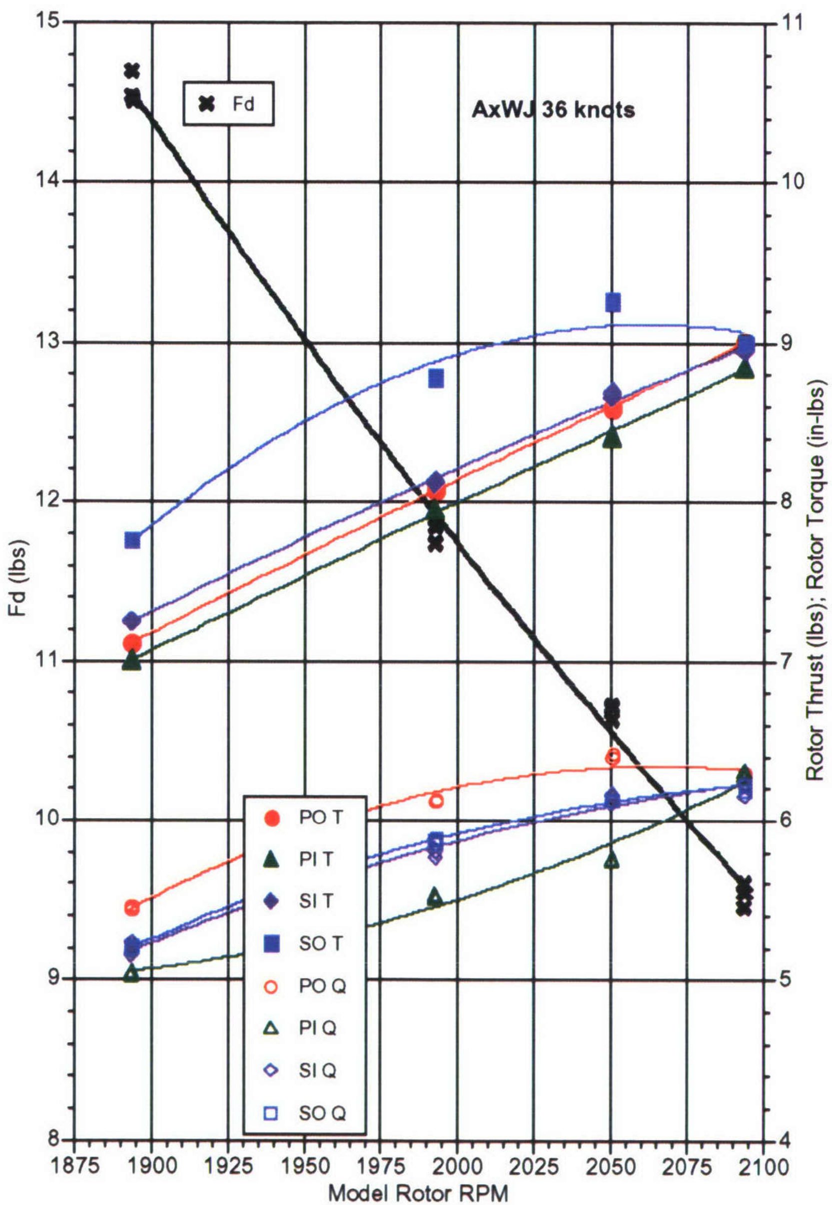


Fig A8. AxWJ over- and under-propelled data, model-scale - continued



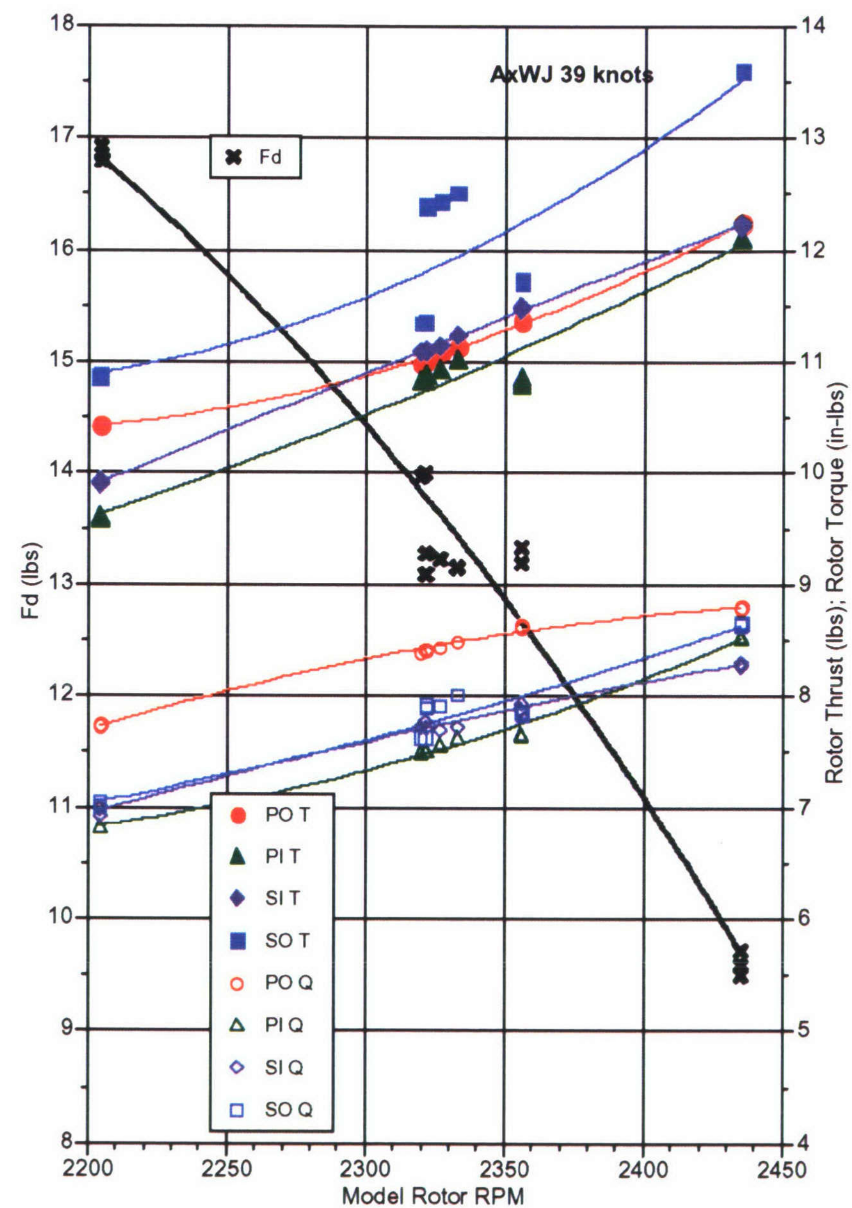


Fig A8. AxWJ over- and under-propelled data, model-scale - continued

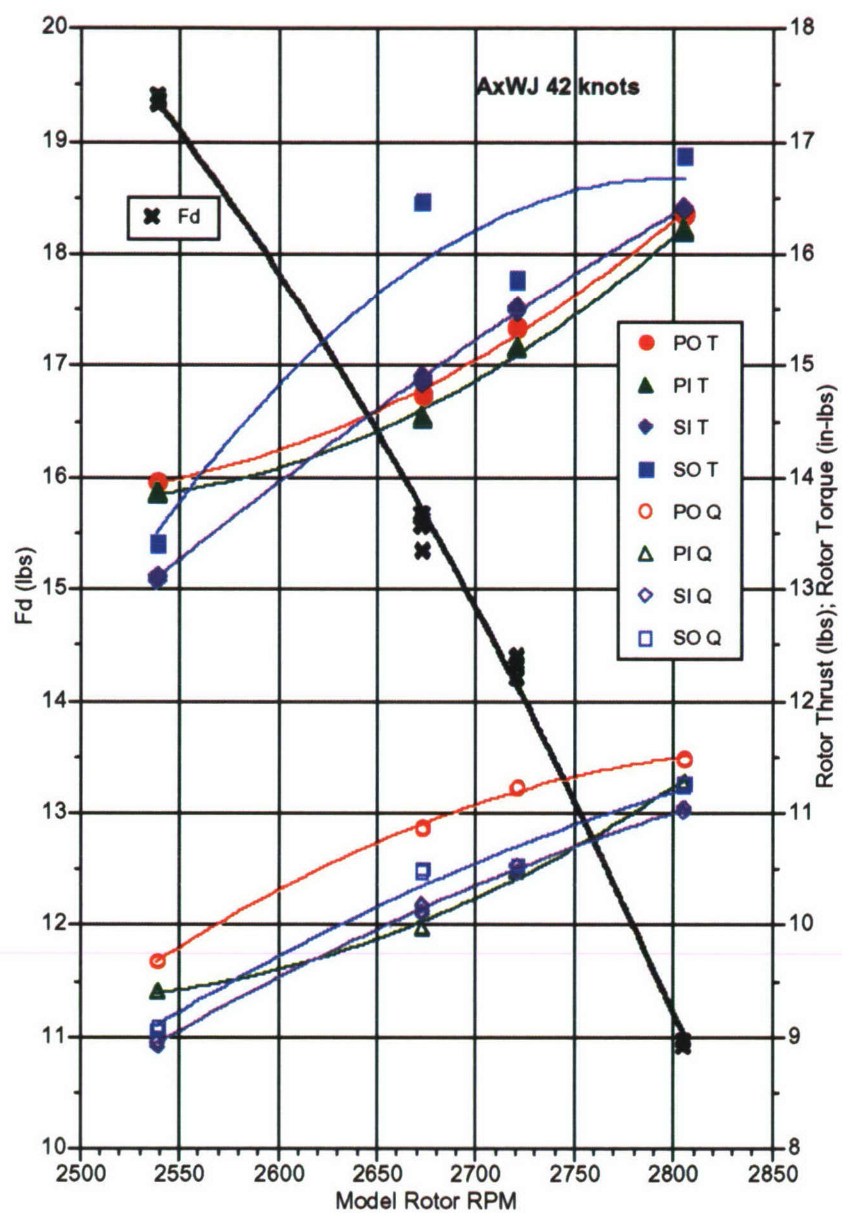


Fig A8. AxWJ over- and under-propelled data, model-scale - continued

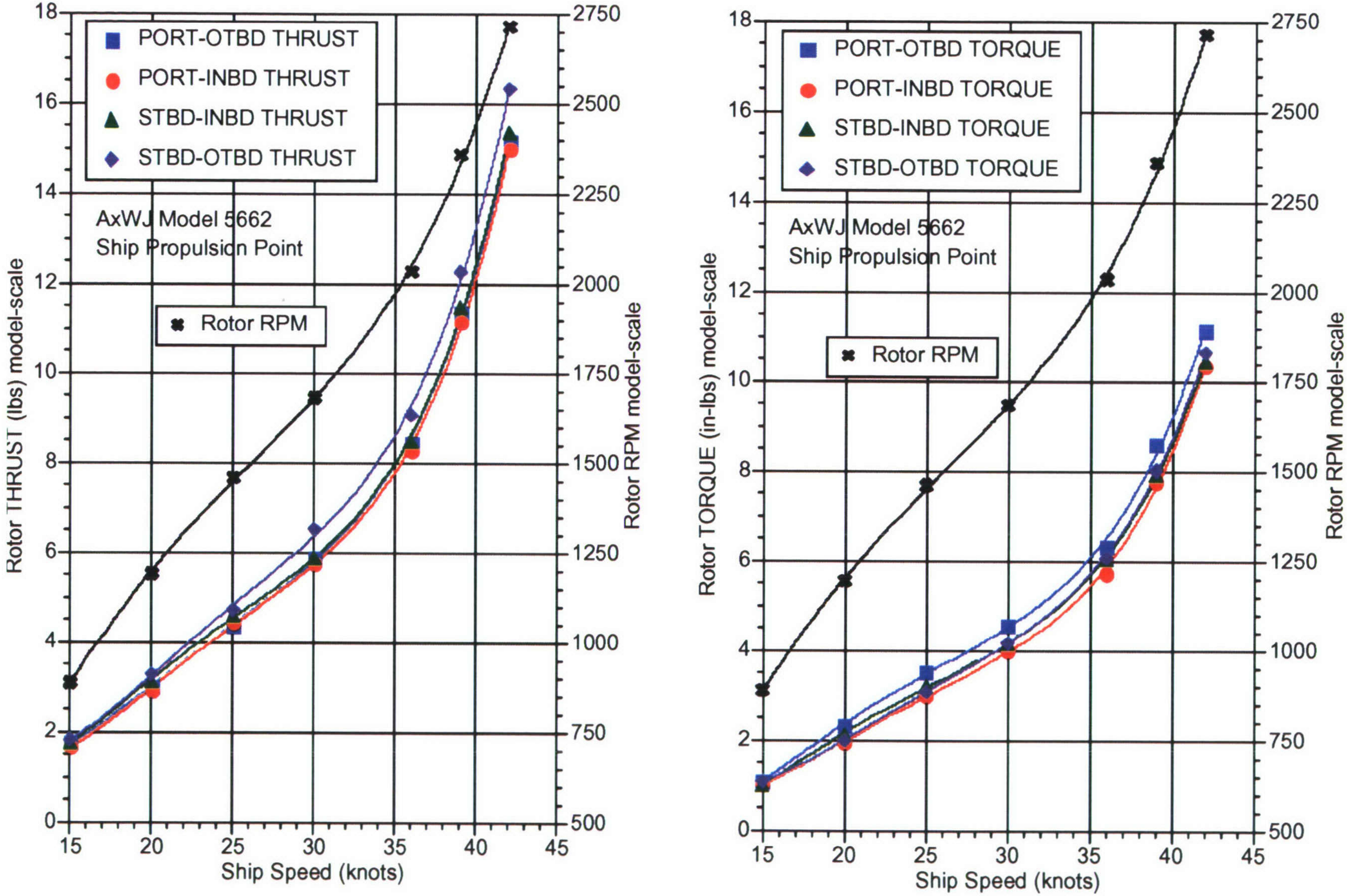


Fig A9. AxWJ model-scale rotor forces at ship propulsion point

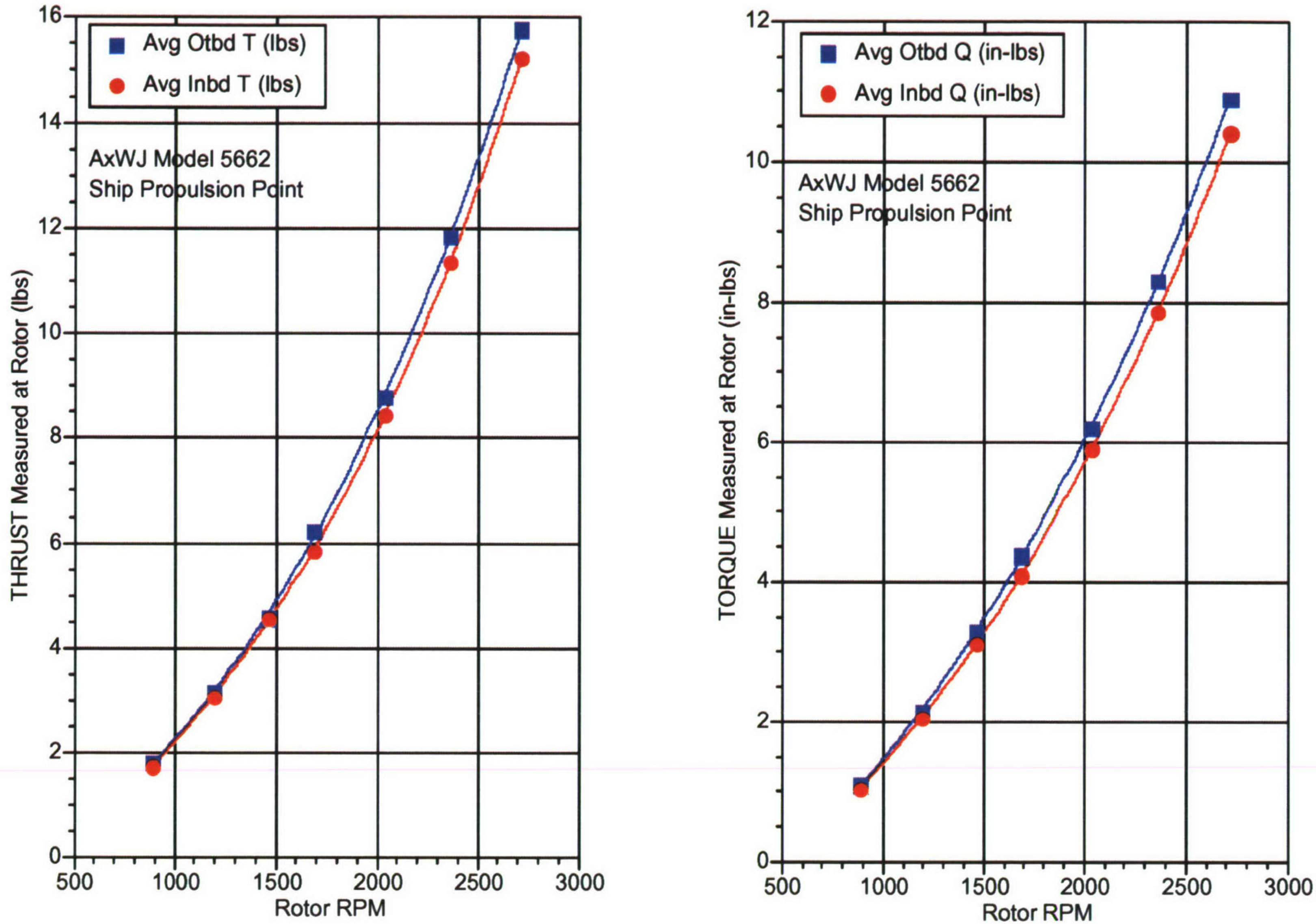


Fig A9. AxWJ model-scale rotor forces at ship propulsion point (continued)

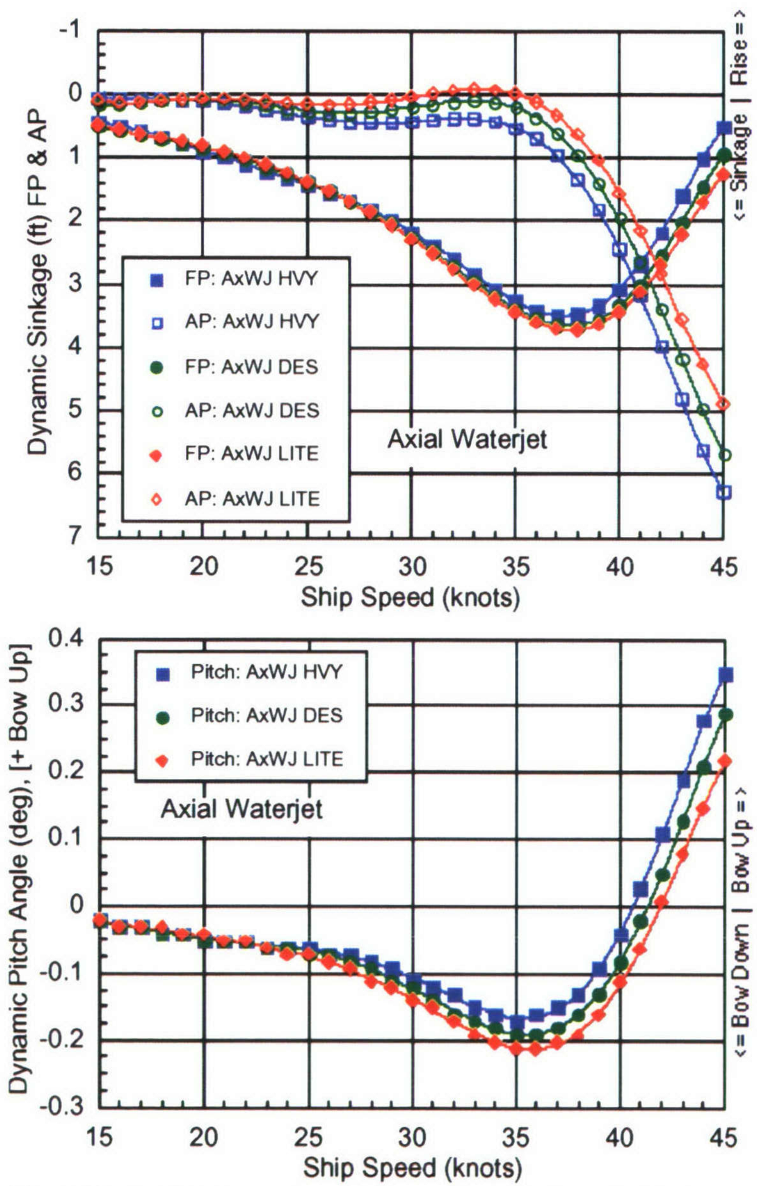


Fig A10. AxWJ dynamic sinkage and pitch, bare hull, three displacements

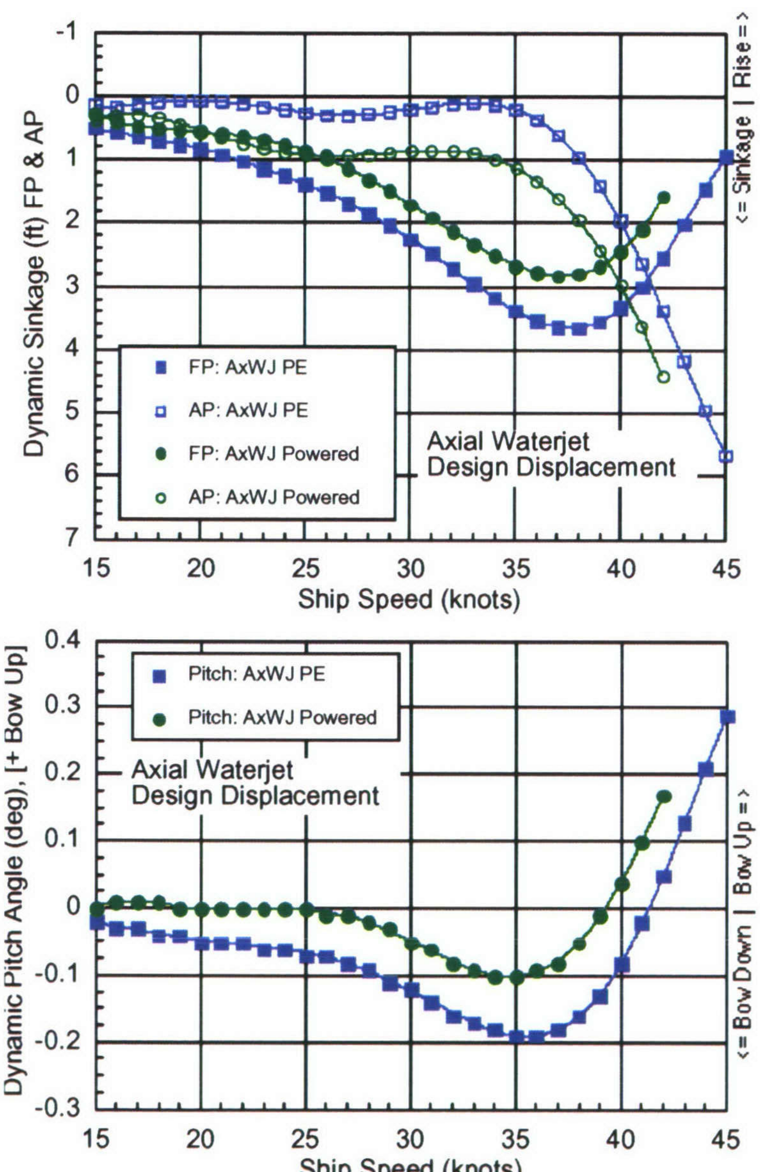


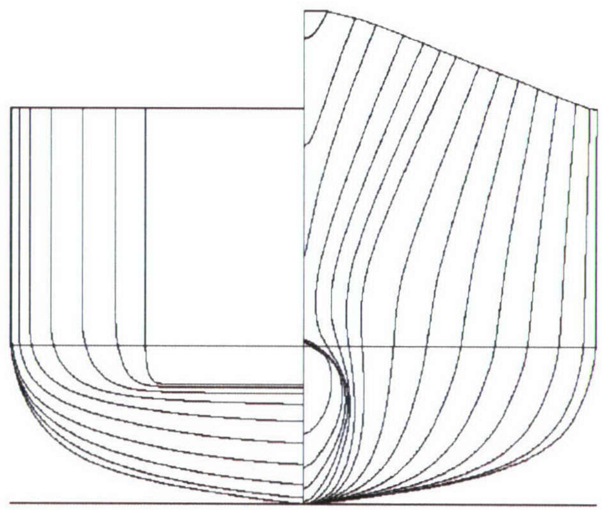
Fig A11. AxWJ dynamic sinkage and pitch, powered vs. unpowered design displacement

Table 1. Test Agenda, AxWJ Model 5662, R&P tests with propulsion nozzles

Day	Date	Model	Test #	Objective	Req. Hours
Series 1 Tests Conducted in 2006					
Wed	12/20/06	AxWJ 5662	1	PE set-up, Check-out, Alignment	1
			2	Heavy EHP [AxWJ GB HVY BH]	4
			3	Design EHP [AxWJ GB DES BH]	4
Thu	12/21/06		4	Light EHP [AxWJ GB LITE BH]	4
Pre-Test		(5) 9-hour days			
Week of 5/7/07		AxWJ 5662	-	Model Rigging Continued. JHSS GB Half-Bow installed on Model 5662. Pressure taps, drive train installation, hardware, instrumentation. Dummy hubs installed on shafts. Inlets covered, transom plate installed. Instrumentation installed on Carriage 2 (if possible).	40
			-	Pre-Test Preparation, calculations, planning.	40
Test Week 1		(5) 9-hour days			
Mon	5/14/07	AxWJ 5662	-	Complete rigging. Model ballasted to DES displacement.	6
			-	Model installed on Carriage 2. PE&PD measurement system Installation, Check-out & Troubleshooting.	3
		MxWJ 5662-1	-	MxWJ Model 5662-1 rigging in parallel with testing. Installation of drive system (minus dynamometers). LDV system fitting & installation. (Mon-Fri)	40
Tue	5/15/07	AxWJ 5662	18	Model Alignment. Data collection troubleshooting.	2
			19	DES Bare Hull EHP Test. Repeat of previous Test 3.	3
			-	Model to Dry-dock. Transom plate removed. Dummy hubs & shafts installed. Four Nozzles installed (with Plugs). Pitot Tubs installed Sta 1.	4
Wed	5/16/07		-	Pitot Tube and pressure system installation, check-out & troubleshooting.	3
			20	DES EHP Test w/ Propulsion Nozzles. Sta 1 pitot measurements.	3
			-	Nozzle plugs removed, Inlets opened (model waterborne).	1
			21	No Loads Conducted, RPMs: 800, 1200, 1600, 2000, 2400, 2800. Transom submerged manually (120lbs).	2
Thr	5/17/07		-	Rotors installed, Nozzles installed with Kiel Probes (waterborne). Pressure system reconfigured.	4
			22	Bollards Conducted, RPMs 1000, 1500, 1750, 2000, 2500, 2800, NO Blocking Board. All 4 jets simultaneously.	2
			23	DES Powering Test, 7 speeds. Kiel probes in Nozzles. Pressure measurements. 4 powering points for all speeds (Fd, previous RPM, over/under +/- 5% RPM).	5
Fri	5/18/07		-	Blocking Board installed.	1
			24	Bollards Conducted, 2 methods. All 4 jets simultaneously, and each jet individually.	4
			-	AxWJ Model 5662 removed from Carriage 2.	2
Test Week 2		(5) 9-hour days			
Mon	5/21/07	AxWJ 5662	-	Model deballasted. Half-Bow separated from AxWJ Model 5662. All hardware and instrumentation removed from AxWJ.	4
			-	Change-Over to MxWJ Model 5662-1	5

Table A2. AxWJ hydrostatic calculations, design displacement

JHSS Axial Waterjet Hull Gooseneck Bulb 06/12/2006



PRINCIPAL DIMENSIONS

LENGTH (LBP)	=	950.51 ft	(289.71 m)
LENGTH (LWL)	=	979.39 ft	(298.52 m)
BEAM (B_X)	=	104.81 ft	(31.95 m)
DRAFT (T_X)	=	28.27 ft	(8.62 m)
TRIM (+Bow)	=	0.00 ft	(0.00 m)
DISPLACEMENT	=	36491.0 T	(37075. t)
WETTED SURFACE	=	96696 sqft	(8983. sqm)

NONDIMENSIONAL COEFFICIENTS

C_B	= 0.440	C_{VP}	= 0.637	L_E/LWL	= 0.530
C_P	= 0.550	C_{VPF}	= 0.807	L_P/LWL	= 0.000
C_{PF}	= 0.498	C_{VPA}	= 0.858	L_R/LWL	= 0.470
C_{PA}	= 0.612	C_S	= 2.735	FB/LWL	= 0.495
C_{PE}	= 0.521	LWL/B_X	= 9.344	FF/LWL	= 0.563
C_{PR}	= 0.581	B_X/T_X	= 3.707	$100C_\nabla$	= 0.136
C_X	= 0.800	A_T/A_X	= 0.163	$\Delta/(.01LWL)^3$	= 38.8
C_{WP}	= 0.690	B_T/B_X	= 0.540	i_E	= 3.95
C_{WPF}	= 0.494	T_T/T_X	= 0.247	i_R	= 6.87
C_{WPA}	= 0.902	A_B/A_X	= 0.115	i_B	= 1.25

MODEL SCALE DATA

SCALE RATIO	=	34.121	
LENGTH (LBP)	=	27.86 ft	(8.49 m)
LENGTH (LWL)	=	28.70 ft	(8.75 m)
BEAM (B_X)	=	3.07 ft	(0.94 m)
DRAFT (T_X)	=	0.83 ft	(0.25 m)
DISPLACEMENT	=	2001.1 lbs	(0.91 t)
WETTED SURFACE	=	83.06 sqft	(7.72 sqm)

Table A3. AxWJ ship/model test parameters, three displacements

Axial Waterjet (AxWJ) Gooseneck Bulb (GB)	Design (DES) 36491 tons		Heavy (HVY) +10% 40140 tons		Light (LITE) -10% 32841 tons	
Model 5662	SHIP	MODEL	SHIP	MODEL		
MODEL SCALE RATIO	-	34.121	-	34.121	-	34.121
LOA (ft)	977.5	28.648	977.5	28.648	977.5	28.648
LBP (ft)	950.5	27.857	950.5	27.857	950.5	27.857
LWL (ft)	979.4	28.703	948.5	27.798	981.6	28.769
WET SURF HULL(sq ft)	96696	83.055	100380	86.219	92896	79.791
WET SURF APP(sq ft)	0	0.000	0	0.000	0	0.000
TOTAL WET SURF(sq ft)	96696	83.055	100380	86.219	92896	79.791
DISPLACEMENT (ton, lbs)	36491	2000	40140	2200	32841	1800
BOW DRAFT @FP (ft)	28.27	0.829	30.07	0.881	26.47	0.776
STERN DRAFT @AP (ft)	28.27	0.829	30.07	0.881	26.47	0.776
SHIP TRIM (+ft bow up)	0.00	0.000	0.00	0.000	0.00	0.000
TRIM ANGLE (degrees)	0.00		0.00		0.00	
BEAM (ft)	104.8	3.072	105.0	3.076	104.5	3.062
TEMP (F)	59	70	59	70	59	70
RHO	1.9905	1.9362	1.9905	1.9362	1.9905	1.9362
NU	1.2817	1.0552	1.2817	1.0552	1.2817	1.0552
Bow Deck/Keel (ft)	71.6	2.098	71.6	2.098	71.6	2.098
Pos of Hook fwd of FP (ft)	42.7	1.250	42.7	1.250	42.7	1.250
Stern Deck/Keel (ft)	70.9	2.077	70.9	2.077	70.9	2.077
Pos of Hook aft of AP (ft)	11.4	0.333	11.4	0.333	11.4	0.333
BOW HOOK SETTING (ft)		1.269		1.216		1.322
Hook if at FP (ft)	-	1.269	-	1.216	-	1.322
Hook if at AP (ft)	-	1.248	-	1.195	-	1.301
STERN HOOK SETTING (ft)		1.248		1.195		1.301
ROTOR DIA (ft, in)	9.91	3.485	9.91	3.485	9.91	3.485
NUMBER of BLADES	7	7	7	7	7	7
ROTOR ROTATION	INBD	INBD	INBD	INBD	INBD	INBD
SPEED RANGE, min (kts)	15.0	2.57	15.0	2.57	15.0	2.57
Design Speed (kts)	36.0	6.16	36.0	6.16	36.0	6.16
max (kts)	45.0	7.70	45.0	7.70	45.0	7.70
MODEL DISP desired (lbs)		2000		2200		1800
DISP actual (ton, lbs)	36485	2000	40134	2200	32837	1800
MODEL WEIGHT* (lbs)	-	1310	-	1310	-	1310
Floating Platform (lbs)	-	45	-	45	-	45
BALLAST required (lbs)	-	645	-	845	-	445
delta DISP (ton, lbs)			+ 3649	+200 +10.0%	-3649	-200 -10.0%
APPENDAGES, ws (sqft)	0.0	0.000	0.0	0.000	0.0	0.000
none	0.0	0.000	0.0	0.000	0.0	0.000

Table A4. AxWJ bare hull resistance prediction, DES displacement

JHSS AxWJ GB Exp3&19 BH DES (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	979.4	ft	28.703	ft
S (no Skeg)	96696	ft^2	83.055	ft^2
WT	36491	LT	2000.6	lbs
RHO	1.9905	$(lbf{*}sec^2)/ft^4$	1.9365	$(lbf{*}sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	5441.5	4057.7	3287.9	2451.8	0.133	0.447	0.933
15.0	6558.3	4890.6	4010.8	2990.8	0.143	0.479	0.897
16.0	7835.8	5843.2	4830.4	3602.0	0.152	0.511	0.872
17.0	9299.9	6935.0	5752.4	4289.5	0.162	0.543	0.858
18.0	10977.7	8186.1	6782.4	5057.6	0.171	0.575	0.855
19.0	12893.4	9614.6	7926.2	5910.5	0.181	0.607	0.861
20.0	15064.3	11233.4	9189.2	6852.4	0.190	0.639	0.873
21.0	17496.6	13047.2	10577.1	7887.3	0.200	0.671	0.888
22.0	20183.1	15050.6	12095.3	9019.5	0.209	0.703	0.903
23.0	23102.0	17227.2	13749.5	10253.0	0.219	0.735	0.914
24.0	26219.0	19551.5	15545.0	11591.9	0.228	0.767	0.918
25.0	29491.7	21991.9	17487.3	13040.3	0.238	0.799	0.913
26.0	32877.2	24516.5	19581.9	14602.3	0.247	0.831	0.899
27.0	36342.8	27100.9	21834.2	16281.8	0.257	0.863	0.876
28.0	39878.0	29737.0	24249.5	18082.9	0.266	0.895	0.846
29.0	43507.8	32443.8	26833.2	20009.5	0.276	0.927	0.813
30.0	47305.7	35275.8	29590.7	22065.8	0.285	0.959	0.780
31.0	51403.3	38331.5	32527.3	24255.6	0.295	0.991	0.753
32.0	55997.3	41757.2	35648.3	26583.0	0.304	1.023	0.738
33.0	61347.6	45746.9	38959.0	29051.8	0.314	1.054	0.741
34.0	67769.6	50535.8	42464.7	31666.0	0.323	1.086	0.765
35.0	75614.7	56385.9	46170.7	34429.5	0.333	1.118	0.816
36.0	85241.8	63564.8	50082.1	37346.2	0.342	1.150	0.896
37.0	96979.0	72317.2	54204.2	40420.1	0.352	1.182	1.004
38.0	111077.6	82830.6	58542.2	43655.0	0.361	1.214	1.138
39.0	127665.4	95200.1	63101.4	47054.7	0.371	1.246	1.294
40.0	146705.2	109398.1	67886.9	50623.3	0.380	1.278	1.464
41.0	167971.8	125256.6	72903.9	54364.5	0.390	1.310	1.640
42.0	191064.5	142476.8	78157.6	58282.1	0.399	1.342	1.811
43.0	215477.4	160681.5	83653.0	62380.0	0.409	1.374	1.971
44.0	240758.0	179533.3	89395.4	66662.1	0.418	1.406	2.112
45.0	266792.8	198947.4	95389.8	71132.2	0.428	1.438	2.236

Table A5. AxWJ bare hull resistance prediction, HVY displacement

JHSS AxWJ GB Exp2 BH HVY (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	948.5	ft	27.798	ft
S (no Skeg)	100380	ft^2	86.219	ft^2
WT	40140	LT	2200.7	lbs
RHO	1.9905	$(lbf*sec^2)/ft^4$	1.9365	$(lbf*sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	5427.7	4047.4	3426.3	2555.0	0.135	0.455	0.835
15.0	6631.1	4944.8	4179.5	3116.7	0.145	0.487	0.832
16.0	8021.2	5981.4	5033.5	3753.5	0.155	0.520	0.835
17.0	9615.7	7170.4	5994.2	4469.9	0.164	0.552	0.844
18.0	11445.1	8534.6	7067.5	5270.2	0.174	0.584	0.859
19.0	13549.1	10103.5	8259.2	6158.9	0.184	0.617	0.883
20.0	15968.8	11908.0	9575.2	7140.3	0.193	0.649	0.915
21.0	18738.0	13972.9	11021.3	8218.6	0.203	0.682	0.954
22.0	21872.8	16310.6	12603.2	9398.2	0.213	0.714	0.997
23.0	25364.2	18914.1	14326.7	10683.4	0.222	0.747	1.039
24.0	29174.2	21755.2	16197.4	12078.4	0.232	0.779	1.075
25.0	33237.1	24784.9	18221.1	13587.5	0.242	0.812	1.100
26.0	37467.9	27939.8	20403.4	15214.8	0.251	0.844	1.112
27.0	41777.3	31153.3	22750.0	16964.7	0.261	0.877	1.107
28.0	46092.8	34371.4	25266.4	18841.1	0.271	0.909	1.086
29.0	50383.4	37570.9	27958.3	20848.5	0.280	0.942	1.053
30.0	54686.2	40779.5	30831.2	22990.8	0.290	0.974	1.012
31.0	59129.5	44092.8	33890.6	25272.2	0.300	1.007	0.970
32.0	63948.4	47686.3	37142.2	27696.9	0.309	1.039	0.937
33.0	69488.4	51817.5	40591.4	30269.0	0.319	1.072	0.921
34.0	76191.2	56815.8	44243.7	32992.5	0.328	1.104	0.931
35.0	84560.7	63056.9	48104.5	35871.6	0.338	1.136	0.974
36.0	95106.8	70921.2	52179.5	38910.2	0.348	1.169	1.054
37.0	108271.1	80737.7	56473.9	42112.6	0.357	1.201	1.171
38.0	124339.3	92719.8	60993.3	45482.7	0.367	1.234	1.322
39.0	143357.7	106901.8	65743.0	49024.6	0.377	1.266	1.498
40.0	165075.2	123096.5	70728.5	52742.2	0.386	1.299	1.688
41.0	188946.5	140897.4	75955.1	56639.7	0.396	1.331	1.877
42.0	214246.8	159763.8	81428.2	60721.0	0.406	1.364	2.053
43.0	240363.6	179239.1	87153.2	64990.1	0.415	1.396	2.206
44.0	267355.9	199367.3	93135.4	69451.1	0.425	1.429	2.342
45.0	296892.6	221392.8	99380.2	74107.8	0.435	1.461	2.482

Table A6. AxWJ bare hull resistance prediction, LITE displacement

JHSS AxWJ GB Exp4 BH LITE (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	981.6	ft	28.769	ft
S (no Skeg)	92896	ft^2	79.791	ft^2
WT	32841	LT	1800.5	lbs
RHO	1.9905	$(lbf*sec^2)/ft^4$	1.9365	$(lbf*sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	5234.1	3903.1	3157.8	2354.8	0.133	0.447	0.936
15.0	6153.3	4588.5	3852.1	2872.5	0.142	0.479	0.844
16.0	7225.7	5388.2	4639.3	3459.5	0.152	0.511	0.781
17.0	8524.9	6357.0	5524.8	4119.8	0.161	0.543	0.756
18.0	10066.1	7506.3	6514.1	4857.6	0.171	0.575	0.754
19.0	11987.8	8939.3	7612.6	5676.7	0.180	0.606	0.789
20.0	14118.6	10528.2	8825.7	6581.3	0.190	0.638	0.819
21.0	16217.4	12093.3	10158.7	7575.3	0.199	0.670	0.809
22.0	18357.6	13689.3	11616.9	8662.7	0.209	0.702	0.783
23.0	20587.9	15352.4	13205.6	9847.4	0.218	0.734	0.751
24.0	22955.0	17117.5	14930.1	11133.4	0.228	0.766	0.718
25.0	25511.0	19023.5	16795.7	12524.5	0.237	0.798	0.690
26.0	28303.9	21106.3	18807.4	14024.7	0.247	0.830	0.669
27.0	31347.9	23376.2	20970.6	15637.8	0.256	0.862	0.652
28.0	34634.7	25827.1	23290.4	17367.7	0.266	0.894	0.639
29.0	38164.1	28459.0	25772.0	19218.1	0.275	0.926	0.629
30.0	41929.4	31266.8	28420.4	21193.1	0.285	0.958	0.619
31.0	45967.5	34278.0	31240.9	23296.3	0.294	0.989	0.612
32.0	50411.4	37591.8	34238.5	25531.6	0.304	1.021	0.611
33.0	55408.9	41318.4	37418.2	27902.8	0.313	1.053	0.619
34.0	61250.9	45674.8	40785.3	30413.6	0.323	1.085	0.644
35.0	68237.9	50885.0	44344.7	33067.8	0.332	1.117	0.690
36.0	76820.1	57284.7	48101.4	35869.2	0.342	1.149	0.762
37.0	87333.2	65124.4	52060.5	38821.5	0.351	1.181	0.862
38.0	100109.9	74651.9	56227.1	41928.5	0.361	1.213	0.989
39.0	115257.8	85947.7	60606.0	45193.9	0.370	1.245	1.140
40.0	132615.3	98891.2	65202.2	48621.3	0.380	1.277	1.303
41.0	151836.1	113224.2	70020.8	52214.5	0.389	1.309	1.469
42.0	172220.6	128424.9	75066.7	55977.3	0.399	1.341	1.622
43.0	193106.3	143999.4	80344.9	59913.2	0.408	1.372	1.755
44.0	214306.4	159808.3	85860.2	64026.0	0.418	1.404	1.866
45.0	236794.3	176577.5	91617.6	68319.3	0.427	1.436	1.971

Table A7. AxWJ resistance prediction with propulsion nozzles installed, DES displacement

JJHSS AxWJ GB Exp20 Propulsion Nozzles DES (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	979.4	ft	28.703	ft
S (no Skeg)	96696	ft^2	83.055	ft^2
WT	36491	LT	2000.6	lbs
RHO	1.9905	$(lbf*sec^2)/ft^4$	1.9365	$(lbf*sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	5441.5	4057.7	3287.9	2451.8	0.133	0.447	0.933
15.0	6558.3	4890.6	4010.8	2990.8	0.143	0.479	0.897
16.0	7835.8	5843.2	4830.4	3602.0	0.152	0.511	0.872
17.0	9299.9	6935.0	5752.4	4289.5	0.162	0.543	0.858
18.0	10977.7	8186.1	6782.4	5057.6	0.171	0.575	0.855
19.0	12893.4	9614.6	7926.2	5910.5	0.181	0.607	0.861
20.0	15100.2	11260.3	9189.2	6852.4	0.190	0.639	0.878
21.0	17714.2	13209.5	10577.1	7887.3	0.200	0.671	0.916
22.0	20534.0	15312.2	12095.3	9019.5	0.209	0.703	0.942
23.0	23564.6	17572.1	13749.5	10253.0	0.219	0.735	0.959
24.0	26760.0	19954.9	15545.0	11591.9	0.228	0.767	0.964
25.0	30072.5	22425.0	17487.3	13040.3	0.238	0.799	0.957
26.0	33460.6	24951.6	19581.9	14602.3	0.247	0.831	0.939
27.0	36898.3	27515.0	21834.2	16281.8	0.257	0.863	0.910
28.0	40385.1	30115.2	24249.5	18082.9	0.266	0.895	0.874
29.0	43957.3	32778.9	26833.2	20009.5	0.276	0.927	0.835
30.0	47697.2	35567.8	29590.7	22065.8	0.285	0.959	0.797
31.0	51742.7	38584.5	32527.3	24255.6	0.295	0.991	0.767
32.0	56292.0	41977.0	35648.3	26583.0	0.304	1.023	0.749
33.0	61605.7	45939.3	38959.0	29051.8	0.314	1.054	0.749
34.0	68000.4	50707.9	42464.7	31666.0	0.323	1.086	0.772
35.0	75835.9	56550.8	46170.7	34429.5	0.333	1.118	0.822
36.0	85489.0	63749.2	50082.1	37346.2	0.342	1.150	0.902
37.0	97315.2	72567.9	54204.2	40420.1	0.352	1.182	1.012
38.0	111591.2	83213.6	58542.2	43655.0	0.361	1.214	1.149
39.0	128438.3	95776.4	63101.4	47054.7	0.371	1.246	1.309
40.0	147719.0	110154.1	67886.9	50623.3	0.380	1.278	1.483
41.0	168905.5	125952.8	72903.9	54364.5	0.390	1.310	1.656
42.0	191197.8	142576.2	78157.6	58282.1	0.399	1.342	1.814
43.0	215477.4	160681.5	83653.0	62380.0	0.409	1.374	1.971
44.0	240758.0	179533.3	89395.4	66662.1	0.418	1.406	2.112
45.0	266792.8	198947.4	95389.8	71132.2	0.428	1.438	2.236

Table A8. AxWJ summary and comparisons of resistance predictions

	Exp3&19 BH DES	Exp2 BH HVY	Exp4 BH LITE	Displacement Effects HVY/DES	Displacement Effects LITE/DES	Exp20 Propulsion Nozzles DES	Exp20 Propulsion Nozzles NOZ/DES
Vs (kts)	PE (hP)	PE (hP)	PE (hP)	PE ratio	PE ratio	PE (hP)	PE ratio
14	5441	5428	5234	0.997	0.962	5441	1.0
15	6558	6631	6153	1.011	0.938	6558	1.0
16	7836	8021	7226	1.024	0.922	7836	1.0
17	9300	9616	8525	1.034	0.917	9300	1.0
18	10978	11445	10066	1.043	0.917	10978	1.0
19	12893	13549	11988	1.051	0.930	12893	1.0
20	15064	15969	14119	1.060	0.937	15100	1.002
21	17497	18738	16217	1.071	0.927	17714	1.012
22	20183	21873	18358	1.084	0.910	20534	1.017
23	23102	25364	20588	1.098	0.891	23565	1.020
24	26219	29174	22955	1.113	0.876	26760	1.021
25	29492	33237	25511	1.127	0.865	30072	1.020
26	32877	37468	28304	1.140	0.861	33461	1.018
27	36343	41777	31348	1.150	0.863	36898	1.015
28	39878	46093	34635	1.156	0.869	40385	1.013
29	43508	50383	38164	1.158	0.877	43957	1.010
30	47306	54686	41929	1.156	0.886	47697	1.008
31	51403	59129	45968	1.150	0.894	51743	1.007
32	55997	63948	50411	1.142	0.900	56292	1.005
33	61348	69488	55409	1.133	0.903	61606	1.004
34	67770	76191	61251	1.124	0.904	68000	1.003
35	75615	84561	68238	1.118	0.902	75836	1.003
36	85242	95107	76820	1.116	0.901	85489	1.003
37	96979	108271	87333	1.116	0.901	97315	1.003
38	111078	124339	100110	1.119	0.901	111591	1.005
39	127665	143358	115258	1.123	0.903	128438	1.006
40	146705	165075	132615	1.125	0.904	147719	1.007
41	167972	188946	151836	1.125	0.904	168905	1.006
42	191065	214247	172221	1.121	0.901	191198	1.001
43	215477	240364	193106	1.115	0.896	215477	1.0
44	240758	267356	214306	1.110	0.890	240758	1.0
45	266793	296893	236794	1.113	0.888	266793	1.0

Table A9. AxWJ over- and under-propelled data, model-scale rotor forces

AxWJ: 15 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	918	1.85	1.79	1.87	1.84	2.02	1.37	1.35	0.93	1.08
+2.5% RPM	896	2.16	1.78	1.73	1.79	1.89	1.16	1.12	1.00	1.10
Tested Fd	874	**2.44**	1.73	1.62	1.74	1.77	1.02	0.97	1.01	1.07
-2.5% RPM	852	2.68	1.65	1.53	1.68	1.68	0.96	0.92	0.97	0.99
-5% RPM	830	2.88	1.53	1.47	1.61	1.61	0.98	0.96	0.87	0.88

AxWJ: 20 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	1233	3.16	3.19	3.30	3.27	3.32	2.01	2.37	2.08	2.00
+2.5% RPM	1203	3.63	3.07	3.04	3.18	3.33	2.26	2.05	2.13	2.00
Tested Fd	1174	**4.07**	2.93	2.84	3.07	3.26	2.35	1.85	2.10	1.95
-2.5% RPM	1145	4.50	2.76	2.70	2.94	3.13	2.28	1.76	2.01	1.85
-5% RPM	1115	4.90	2.56	2.62	2.80	2.92	2.04	1.78	1.85	1.70

AxWJ: 25 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	1511	4.34	5.00	4.79	4.85	5.37	3.42	3.37	3.30	3.33
+2.5% RPM	1475	5.33	4.55	4.56	4.71	4.90	3.53	3.09	3.25	3.15
Tested Fd	1439	**6.07**	4.20	4.32	4.48	4.55	3.43	2.90	3.11	2.98
-2.5% RPM	1403	6.57	3.94	4.06	4.17	4.33	3.12	2.82	2.88	2.81
-5% RPM	1367	6.82	3.78	3.79	3.78	4.24	2.59	2.83	2.56	2.65

AxWJ: 30 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	1740	6.33	6.68	6.21	6.25	7.04	4.40	4.43	4.29	4.42
+2.5% RPM	1698	7.45	6.10	5.89	6.02	6.70	4.56	4.11	4.22	4.25
Tested Fd	1657	**8.44**	5.62	5.57	5.72	6.33	4.48	3.86	4.05	4.05
-2.5% RPM	1616	9.30	5.23	5.24	5.36	5.94	4.13	3.70	3.80	3.82
-5% RPM	1574	10.04	4.94	4.90	4.94	5.52	3.54	3.63	3.46	3.56

Table A9. AxWJ over- and under-propelled data, model-scale rotor forces - continued

AxWJ: 36 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	2104	9.38	9.10	8.93	9.06	9.04	6.31	6.35	6.26	6.24
+2.5% RPM	2054	10.47	8.65	8.48	8.67	9.12	6.34	5.89	6.11	6.13
Tested Fd	2004	**11.65**	8.18	8.03	8.25	8.95	6.23	5.53	5.89	5.94
-2.5% RPM	1954	12.92	7.71	7.57	7.81	8.55	5.97	5.26	5.61	5.66
-5% RPM	1904	14.28	7.22	7.10	7.35	7.91	5.55	5.09	5.26	5.29

AxWJ: 39 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	2447	9.21	12.42	12.22	12.36	13.76	8.84	8.66	8.35	8.74
+2.5% RPM	2389	11.50	11.70	11.50	11.79	12.73	8.70	8.05	8.08	8.25
Tested Fd	2331	**13.50**	11.13	10.85	11.21	11.92	8.49	7.55	7.77	7.82
-2.5% RPM	2272	15.20	10.72	10.25	10.62	11.33	8.19	7.16	7.43	7.44
-5% RPM	2214	16.60	10.46	9.72	10.02	10.95	7.81	6.88	7.04	7.11

AxWJ: 42 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	2817	10.55	16.55	16.43	16.54	16.66	11.51	11.44	11.10	11.27
+2.5% RPM	2750	13.11	15.61	15.45	15.81	16.56	11.31	10.69	10.70	10.89
Tested Fd	2683	**15.40**	14.87	14.69	15.02	16.04	10.96	10.10	10.22	10.42
-2.5% RPM	2615	17.40	14.33	14.17	14.16	15.10	10.45	9.68	9.67	9.86
-5% RPM	2548	19.12	13.98	13.88	13.24	13.74	9.78	9.42	9.04	9.21

Table A10. AxWJ model-scale rotor forces at ship propulsion point

JHSS AxWJ Rotor Forces at Ship Propulsion Point										
Ship Speed (knots)	Rotor RPM	FD (lbs)	1 Port Out T (lbs)	2 Port In T (lbs)	3 Stbd In T (lbs)	4 Stbd Out T (lbs)	1 Port Out Q (in-lbs)	2 Port In Q (in-lbs)	3 Stbd In Q (in-lbs)	4 Stbd Out Q (in-lbs)
15	887.0	2.28	1.76	1.68	1.77	1.84	1.09	1.05	1.01	1.09
20	1191.5	3.81	3.02	2.95	3.14	3.31	2.32	1.96	2.13	1.99
25	1460.0	5.67	4.39	4.46	4.62	4.74	3.52	3.00	3.20	3.08
30	1681.8	7.86	5.89	5.76	5.91	6.55	4.56	4.00	4.16	4.17
36	2035.3	10.90	8.47	8.31	8.51	9.08	6.32	5.74	6.04	6.07
39	2358.8	12.58	11.38	11.16	11.49	12.29	8.60	7.78	7.92	8.02
42	2713.8	14.37	15.19	15.02	15.39	16.34	11.14	10.35	10.45	10.65

JHSS AxWJ Rotor Forces at Ship Propulsion Point					
Ship Speed (knots)	Rotor RPM	1&4 Avg Otbd T (lbs)	2&3 Avg Inbd T (lbs)	1&4 Avg Otbd Q (in-lbs)	2&3 Avg Inbd Q (in-lbs)
15	887.0	1.80	1.72	1.09	1.03
20	1191.5	3.16	3.04	2.15	2.04
25	1460.0	4.56	4.54	3.30	3.10
30	1681.8	6.22	5.83	4.37	4.08
36	2035.3	8.78	8.41	6.20	5.89
39	2358.8	11.83	11.33	8.31	7.85
42	2713.8	15.76	15.21	10.90	10.40

Table A10. AxWJ model-scale rotor forces at ship propulsion point (continued)

JHSS AxWJ Rotor Forces at Previously Tested Fd Values										
Ship			1	2	3	4	1	2	3	4
Speed (knots)	Rotor RPM	FD (lbs)	Port Out T (lbs)	Port In T (lbs)	Stbd In T (lbs)	Stbd Out T (lbs)	Port Out Q (in-lbs)	Port In Q (in-lbs)	Stbd In Q (in-lbs)	Stbd Out Q (in-lbs)
15	874.0	2.44	1.73	1.62	1.74	1.77	1.02	0.97	1.01	1.07
20	1174.0	4.07	2.93	2.84	3.07	3.26	2.35	1.85	2.10	1.95
25	1439.0	6.07	4.20	4.32	4.48	4.55	3.43	2.90	3.11	2.98
30	1657.0	8.44	5.62	5.57	5.72	6.33	4.48	3.86	4.05	4.05
36	2004.0	11.65	8.18	8.03	8.25	8.95	6.23	5.53	5.89	5.94
39	2330.8	13.50	11.13	10.85	11.21	11.92	8.49	7.55	7.77	7.82
42	2682.5	15.40	14.87	14.69	15.02	16.04	10.96	10.10	10.22	10.42

Delta (Δ) Differences in Rotor Forces Ship Propulsion Point vs. Previously Tested Values										
Ship			1	2	3	4	1	2	3	4
Speed (knots)	Rotor Δ RPM	FD Δ FD	Port Out Δ T	Port In Δ T	Stbd In Δ T	Stbd Out Δ T	Port Out Δ Q	Port In Δ Q	Stbd In Δ Q	Stbd Out Δ Q
15	1.5%	-6.6%	1.9%	3.9%	1.9%	3.6%	7.0%	7.5%	-0.2%	2.1%
20	1.5%	-6.6%	3.1%	4.0%	2.2%	1.4%	-1.4%	5.9%	1.0%	1.8%
25	1.5%	-6.6%	4.6%	3.3%	3.1%	4.1%	2.5%	3.3%	3.0%	3.3%
30	1.5%	-6.6%	4.9%	3.5%	3.2%	3.5%	1.9%	3.5%	2.7%	3.1%
36	1.6%	-6.6%	3.6%	3.5%	3.2%	1.5%	1.4%	3.9%	2.4%	2.2%
39	1.2%	-6.6%	2.3%	2.8%	2.5%	3.0%	1.3%	3.0%	2.0%	2.6%
42	1.2%	-6.6%	2.2%	2.2%	2.5%	1.8%	1.7%	2.5%	2.3%	2.2%

Table A11. AxWJ dynamic sinkage and pitch, bare hull, three displacements

	Axial Waterjet (AxWJ) Bare Hull								
	Heavy (HVY)			Design (DES)			Light (LITE)		
VS (Knots)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)
15	0.43	0.05	-0.02	0.50	0.14	-0.02	0.48	0.09	-0.02
16	0.50	0.07	-0.03	0.57	0.16	-0.03	0.56	0.13	-0.03
17	0.58	0.08	-0.03	0.63	0.13	-0.03	0.62	0.12	-0.03
18	0.67	0.07	-0.04	0.68	0.09	-0.04	0.67	0.09	-0.03
19	0.77	0.08	-0.04	0.75	0.06	-0.04	0.73	0.07	-0.04
20	0.88	0.10	-0.05	0.82	0.06	-0.05	0.80	0.06	-0.04
21	0.98	0.13	-0.05	0.91	0.07	-0.05	0.88	0.06	-0.05
22	1.09	0.18	-0.05	1.01	0.11	-0.05	0.98	0.08	-0.05
23	1.20	0.24	-0.06	1.12	0.16	-0.06	1.10	0.10	-0.06
24	1.30	0.30	-0.06	1.24	0.21	-0.06	1.22	0.12	-0.07
25	1.41	0.35	-0.06	1.37	0.25	-0.07	1.36	0.14	-0.07
26	1.53	0.40	-0.07	1.51	0.28	-0.07	1.51	0.15	-0.08
27	1.66	0.43	-0.07	1.67	0.29	-0.08	1.68	0.14	-0.09
28	1.80	0.44	-0.08	1.84	0.27	-0.09	1.86	0.11	-0.11
29	1.97	0.44	-0.09	2.03	0.24	-0.11	2.06	0.07	-0.12
30	2.17	0.42	-0.11	2.24	0.20	-0.12	2.28	0.02	-0.14
31	2.38	0.40	-0.12	2.46	0.15	-0.14	2.51	-0.03	-0.15
32	2.61	0.38	-0.13	2.70	0.11	-0.16	2.75	-0.08	-0.17
33	2.84	0.38	-0.15	2.94	0.09	-0.17	2.99	-0.10	-0.19
34	3.06	0.42	-0.16	3.17	0.12	-0.18	3.22	-0.09	-0.20
35	3.26	0.52	-0.17	3.37	0.20	-0.19	3.42	-0.03	-0.21
36	3.41	0.69	-0.16	3.53	0.35	-0.19	3.58	0.10	-0.21
37	3.48	0.95	-0.15	3.63	0.59	-0.18	3.68	0.31	-0.20
38	3.46	1.32	-0.13	3.64	0.94	-0.16	3.69	0.61	-0.19
39	3.33	1.81	-0.09	3.54	1.39	-0.13	3.61	1.02	-0.16
40	3.06	2.43	-0.04	3.33	1.95	-0.08	3.41	1.53	-0.11
41	2.67	3.15	0.03	2.99	2.62	-0.02	3.10	2.13	-0.06
42	2.17	3.95	0.11	2.54	3.36	0.05	2.68	2.81	0.01
43	1.58	4.79	0.19	2.00	4.15	0.13	2.19	3.53	0.08
44	0.99	5.59	0.28	1.44	4.93	0.21	1.68	4.23	0.15
45	0.50	6.26	0.35	0.93	5.65	0.29	1.24	4.85	0.22

Table A12. AxWJ dynamic sinkage and pitch, powered vs. unpowered, design displacement

	Axial Waterjet (AxWJ), Design (DES) Displacement					
	Bare Hull (Unpowered)			Waterjet Powered		
VS (Knots)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)
15	0.50	0.14	-0.02	0.27	0.36	0.00
16	0.57	0.16	-0.03	0.39	0.28	0.01
17	0.63	0.13	-0.03	0.46	0.28	0.01
18	0.68	0.09	-0.04	0.50	0.33	0.01
19	0.75	0.06	-0.04	0.53	0.43	0.00
20	0.82	0.06	-0.05	0.55	0.53	0.00
21	0.91	0.07	-0.05	0.58	0.64	0.00
22	1.01	0.11	-0.05	0.62	0.73	0.00
23	1.12	0.16	-0.06	0.67	0.81	0.00
24	1.24	0.21	-0.06	0.75	0.87	0.00
25	1.37	0.25	-0.07	0.85	0.91	0.00
26	1.51	0.28	-0.07	0.97	0.92	-0.01
27	1.67	0.29	-0.08	1.12	0.92	-0.01
28	1.84	0.27	-0.09	1.29	0.90	-0.02
29	2.03	0.24	-0.11	1.48	0.88	-0.03
30	2.24	0.20	-0.12	1.69	0.85	-0.05
31	2.46	0.15	-0.14	1.90	0.84	-0.06
32	2.70	0.11	-0.16	2.12	0.85	-0.08
33	2.94	0.09	-0.17	2.32	0.89	-0.09
34	3.17	0.12	-0.18	2.51	0.97	-0.10
35	3.37	0.20	-0.19	2.66	1.11	-0.10
36	3.53	0.35	-0.19	2.77	1.31	-0.09
37	3.63	0.59	-0.18	2.82	1.59	-0.08
38	3.64	0.94	-0.16	2.79	1.95	-0.05
39	3.54	1.39	-0.13	2.67	2.40	-0.01
40	3.33	1.95	-0.08	2.44	2.96	0.04
41	2.99	2.62	-0.02	2.08	3.61	0.10
42	2.54	3.36	0.05	1.56	4.38	0.17
43	2.00	4.15	0.13			
44	1.44	4.93	0.21			
45	0.93	5.65	0.29			

Table A13. AxWJ Model 5662 measurement uncertainties

25 knot Ship Speed							
	Units	Nominal	Bias	Precision	Uncertainty		Four Shafts
Measurement		Mean	Error	Error	(units)	(percent)	(percent)
			±	±	±	±	±
Speed	ft/sec	7.24	0.002	0.001	0.002	0.03	-
Resistance	lbf	15.19	0.059	0.115	0.129	**0.85**	-
INbd Prop Shaft Rate	RPM	1448.09	0.009	0.365	0.365	0.03	-
OUTbd Prop Shaft Rate	RPM	1448.09	0.009	0.365	0.365	0.03	0.03
INbd Shaft Thrust - combined	lbf	8.90	0.057	0.019	0.060	0.68	-
OUTbd Shaft Thrust - combined	lbf	8.87	0.057	0.025	0.062	0.70	0.69
INbd Shaft Torque - combined	lbf-in	6.05	0.094	0.037	0.101	1.67	-
OUTbd Shaft Torque - combined	lbf-in	6.66	0.094	0.071	0.118	1.77	1.72
INbd Shaft Power - combined	hP	0.139	0.0022	0.0009	0.0023	1.67	-
OUTbd Shaft Power - combined	hP	0.153	0.0022	0.0016	0.0027	1.77	**1.72**

36 knot Ship Speed							
	Units	Nominal	Bias	Precision	Uncertainty		Four Shafts
Measurement		Mean	Error	Error	(units)	(percent)	(percent)
			±	±	±	±	±
Speed	ft/sec	10.41	0.003	0.000	0.003	0.03	-
Resistance	lbf	29.70	0.063	0.076	0.099	**0.33**	-
INbd Prop Shaft Rate	RPM	1993.04	0.011	0.227	0.227	0.01	-
OUTbd Prop Shaft Rate	RPM	1993.04	0.011	0.227	0.227	0.01	0.01
INbd Shaft Thrust - combined	lbf	16.08	0.059	0.035	0.069	0.43	-
OUTbd Shaft Thrust - combined	lbf	17.19	0.059	0.052	0.079	0.46	0.44
INbd Shaft Torque - combined	lbf-in	11.33	0.095	0.095	0.135	1.19	-
OUTbd Shaft Torque - combined	lbf-in	12.27	0.095	0.058	0.112	0.91	1.05
INbd Shaft Power - combined	hP	0.358	0.0030	0.0030	0.0043	1.19	-
OUTbd Shaft Power - combined	hP	0.388	0.0030	0.0018	0.0035	0.91	**1.05**

Appendix B

Mixed-Flow Waterjet (MxWJ) Model 5662-1 Data

APPENDIX B FIGURES

APPENDIX B TABLES

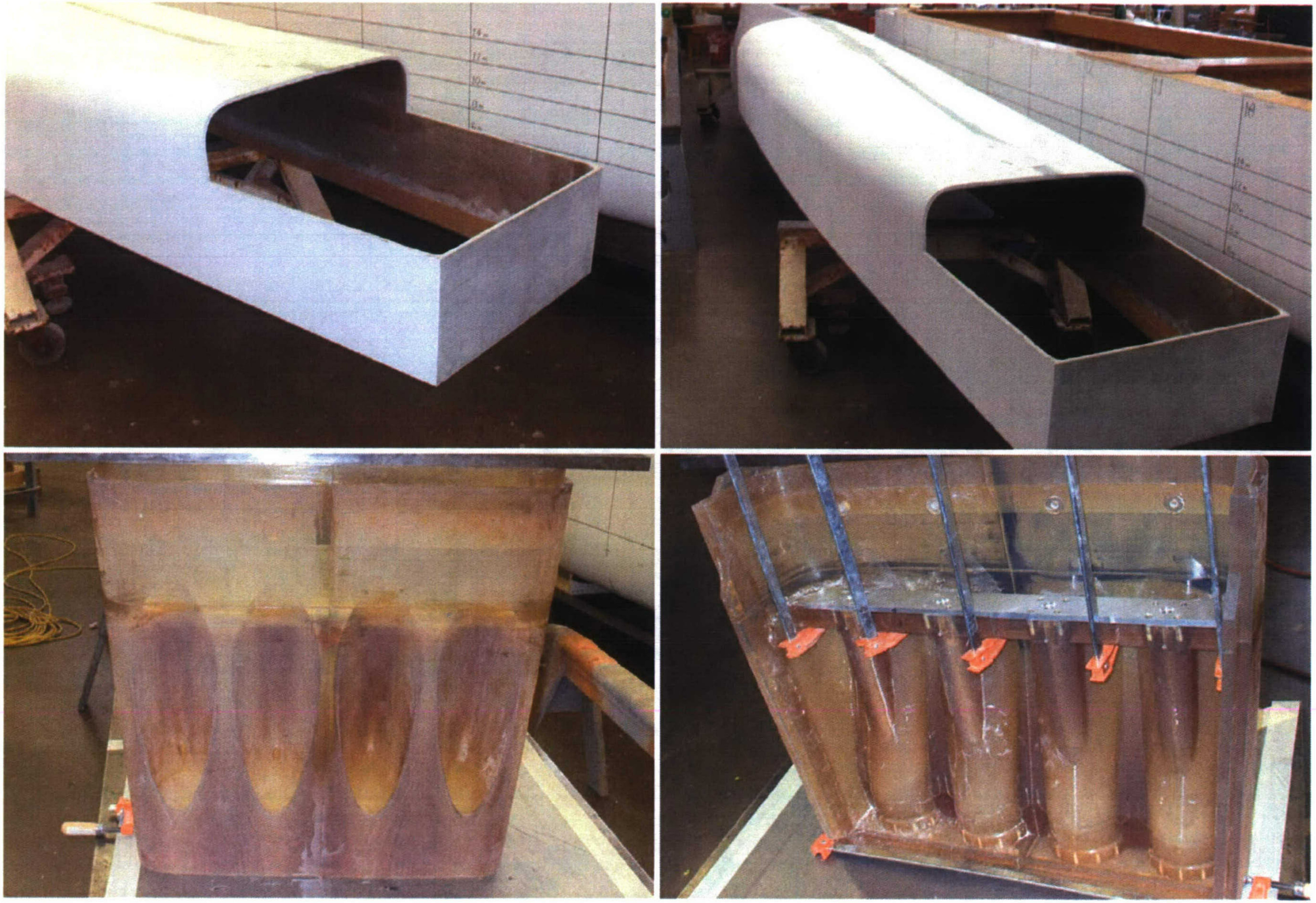


Fig B1. MxWJ Model 5662-1 construction and equipment installation (Feb-June 2007)

Fig B1. MxWJ Model 5662-1 construction and equipment installation (Feb-June 2007) - continued

Fig B1. MxWJ Model 5662-1 construction and equipment installation (Feb-June 2007) - continued

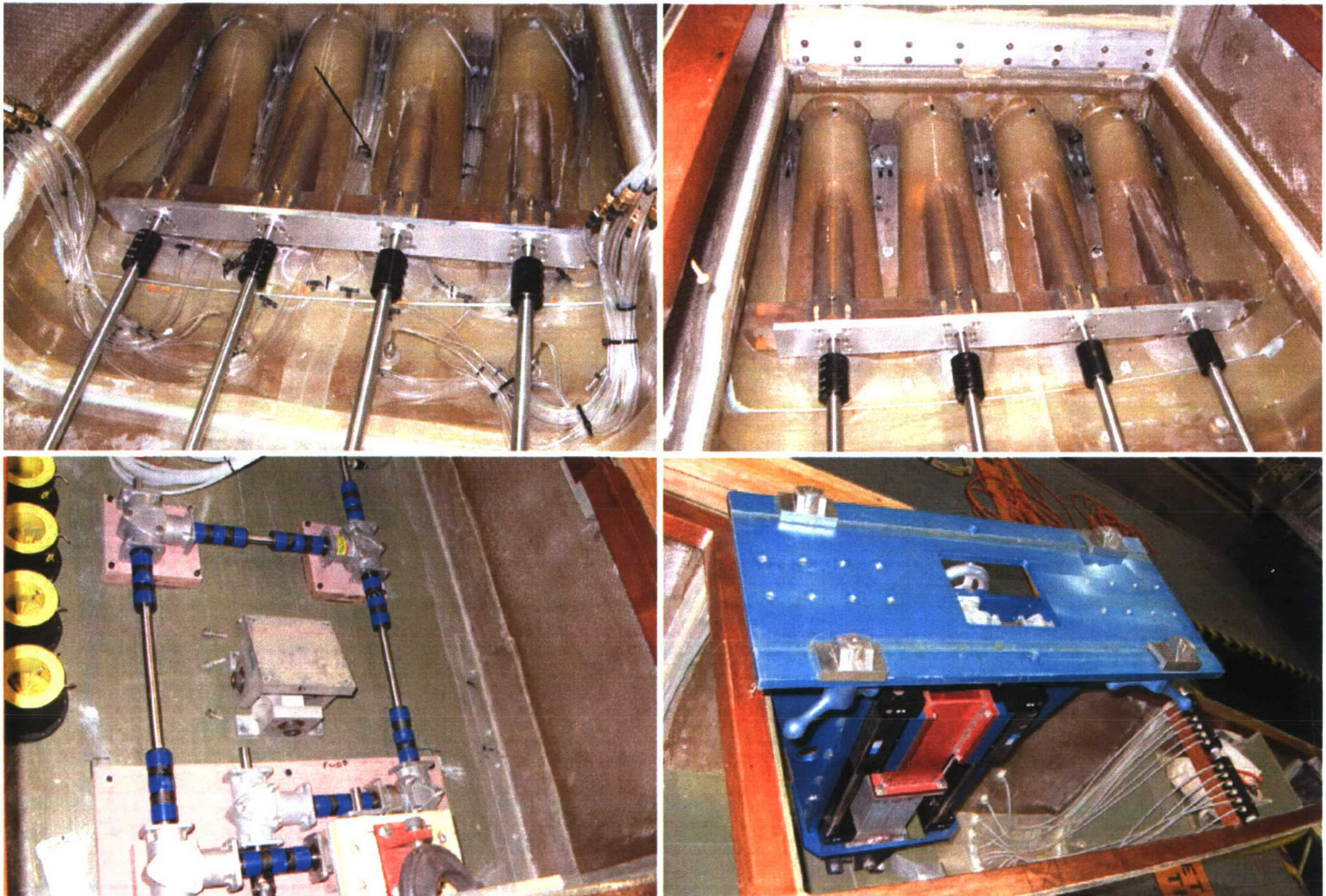


Fig B1. MxWJ Model 5662-1 construction and equipment installation (Feb-June 2007) - continued

Fig B2. MxWJ Bare Hull (June 2007)

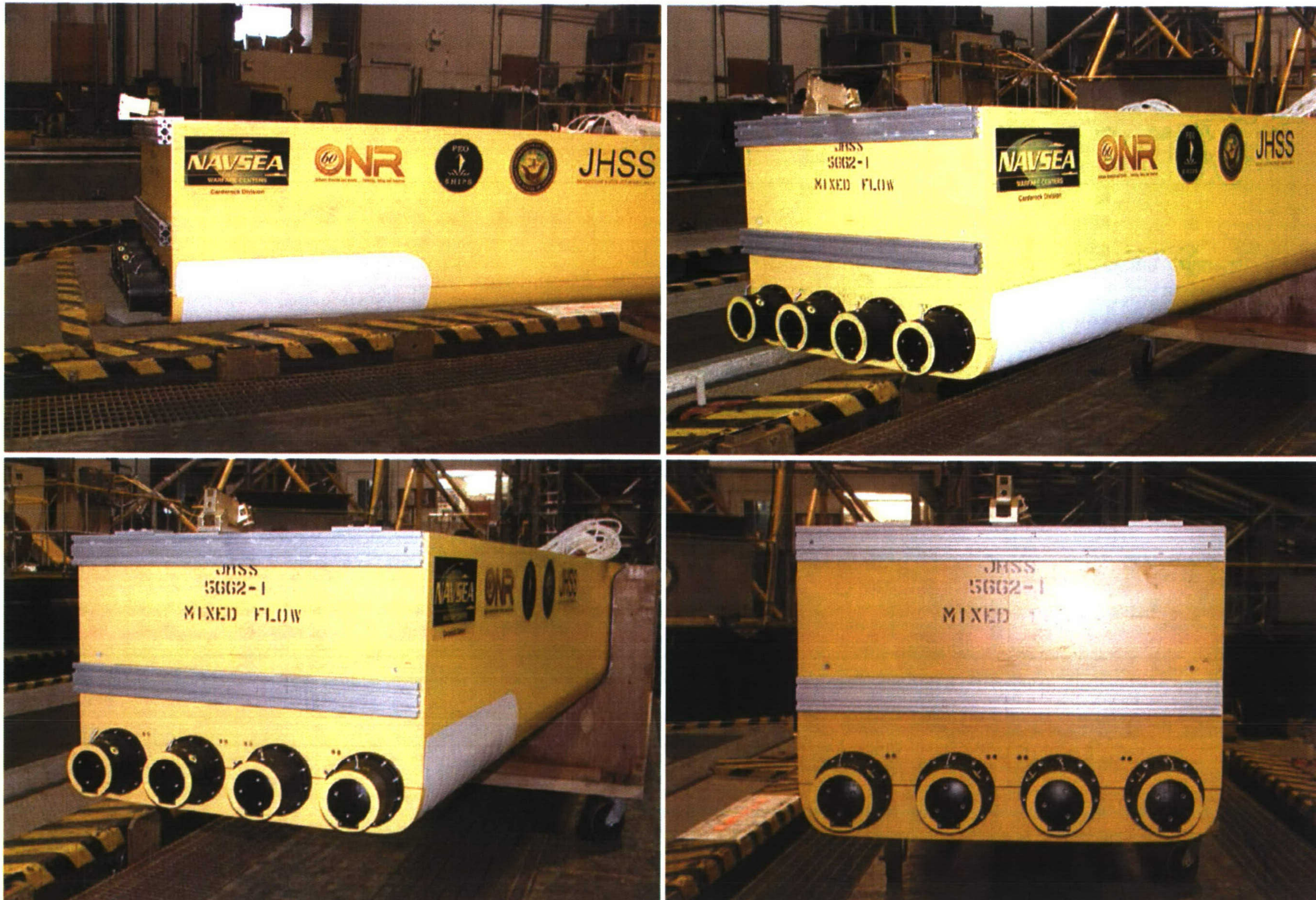


Fig B3. MxWJ Propulsion nozzles installed (June 2007)

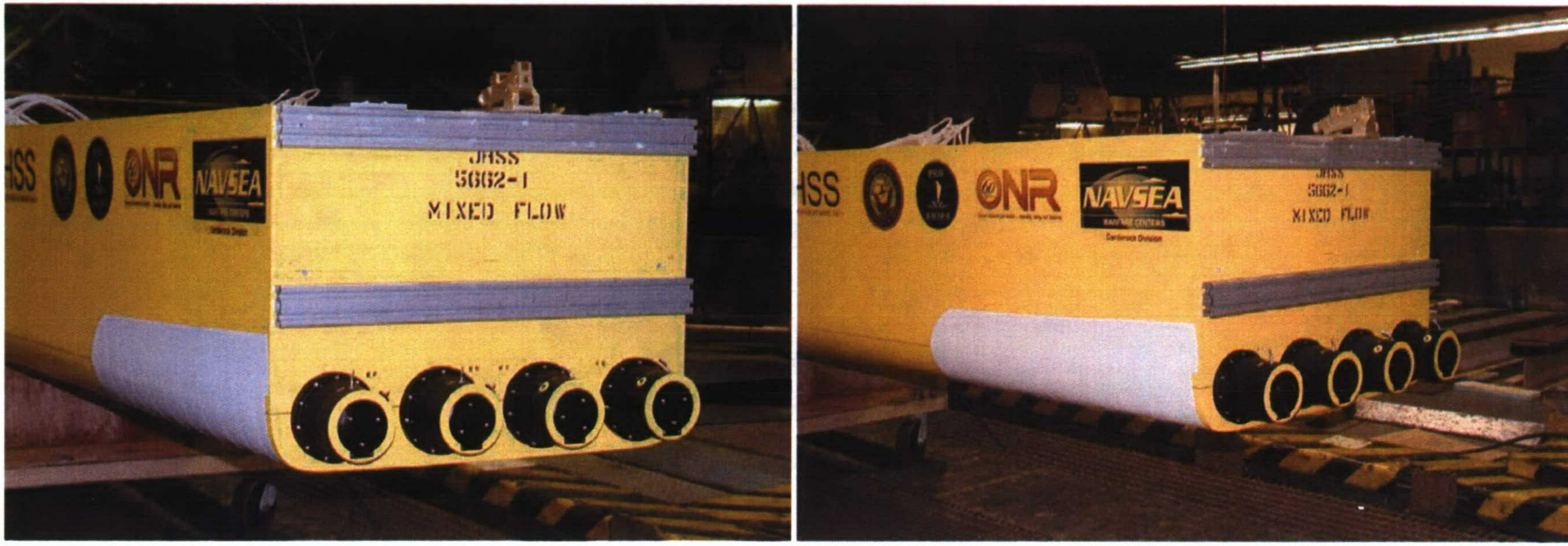


Fig B3. MxWJ Propulsion nozzles installed (June 2007) - continued

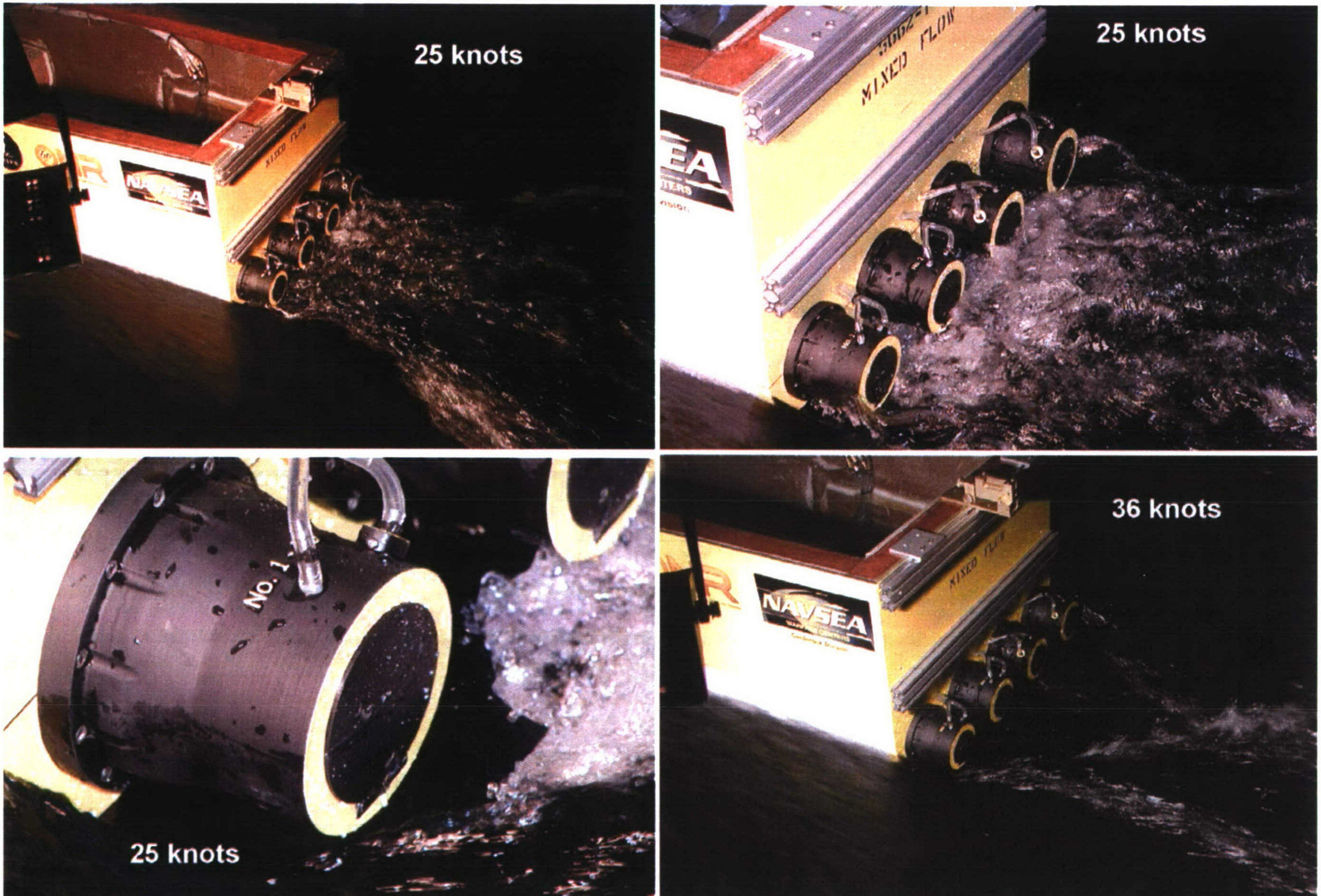
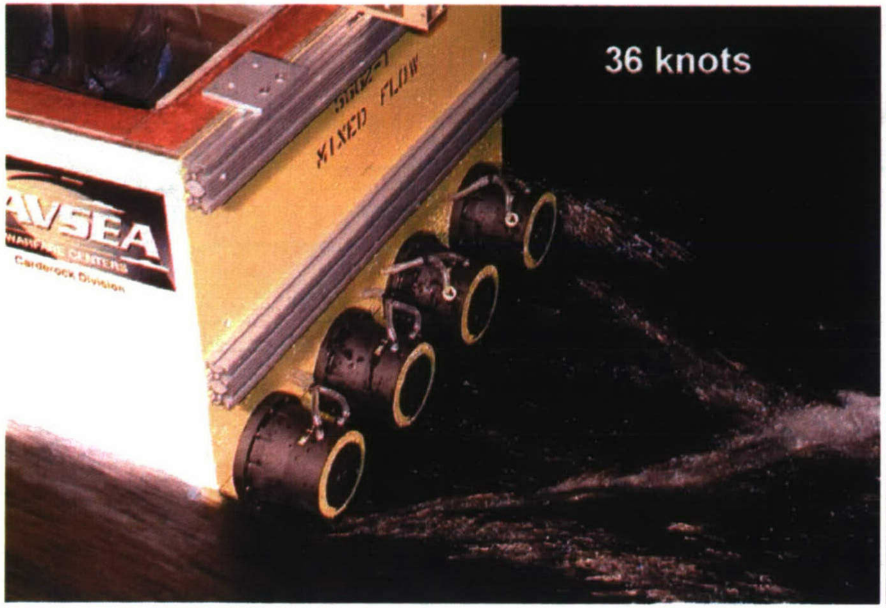


Fig B4. MxWJ Resistance test underway (June 2007)



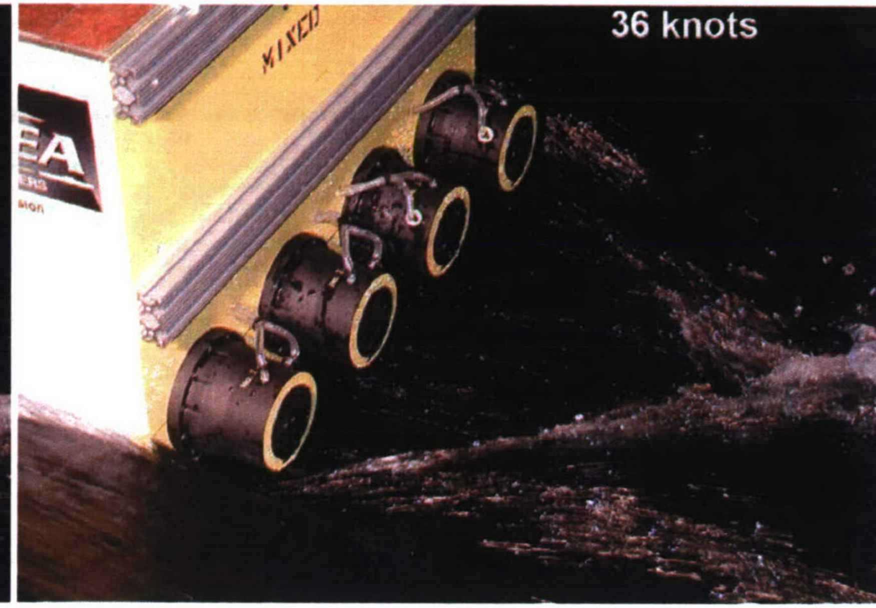


Fig B4. MxWJ Resistance test underway (June 2007) – continued

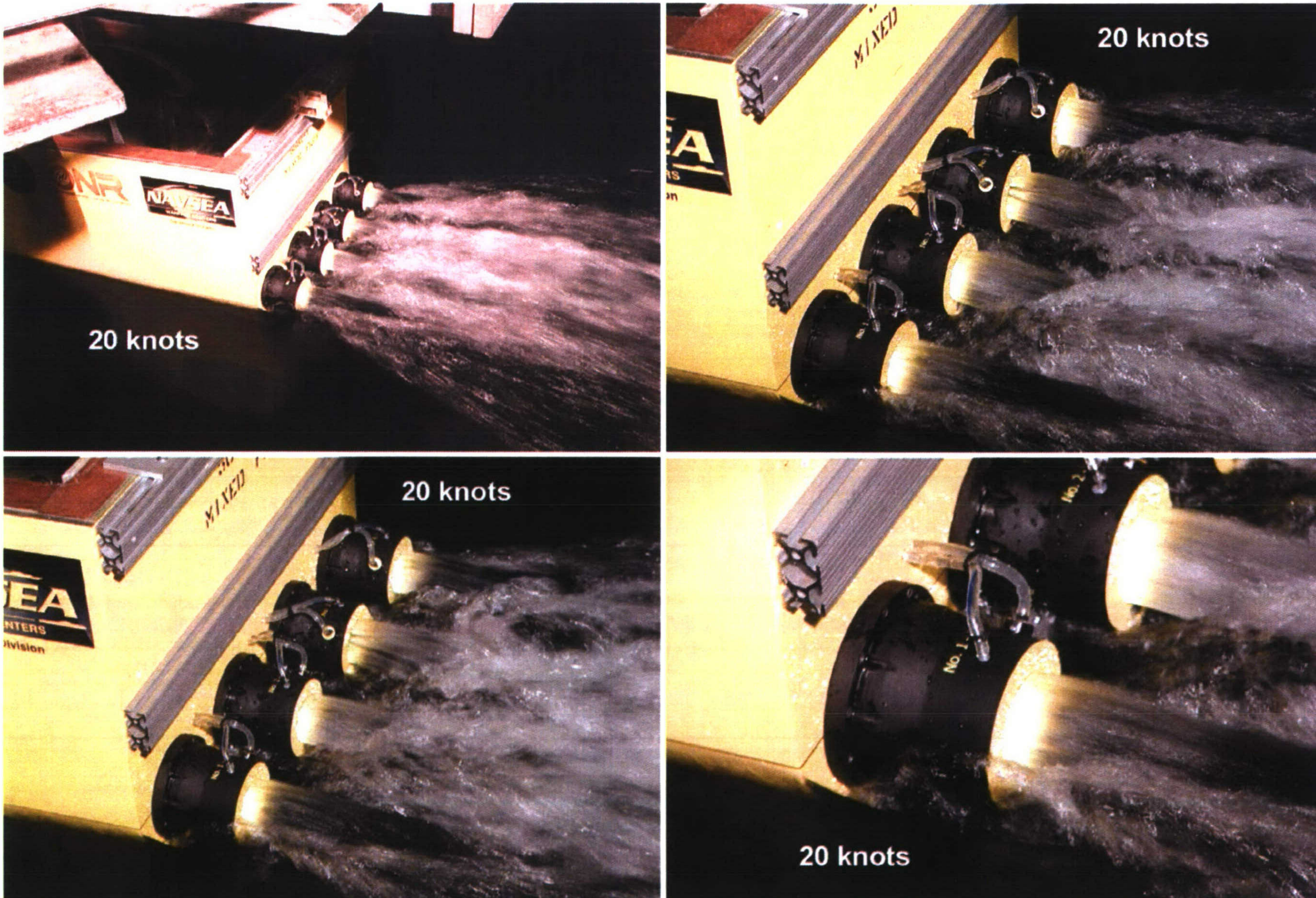


Fig B5. MxWJ Powering test underway (June 2007)

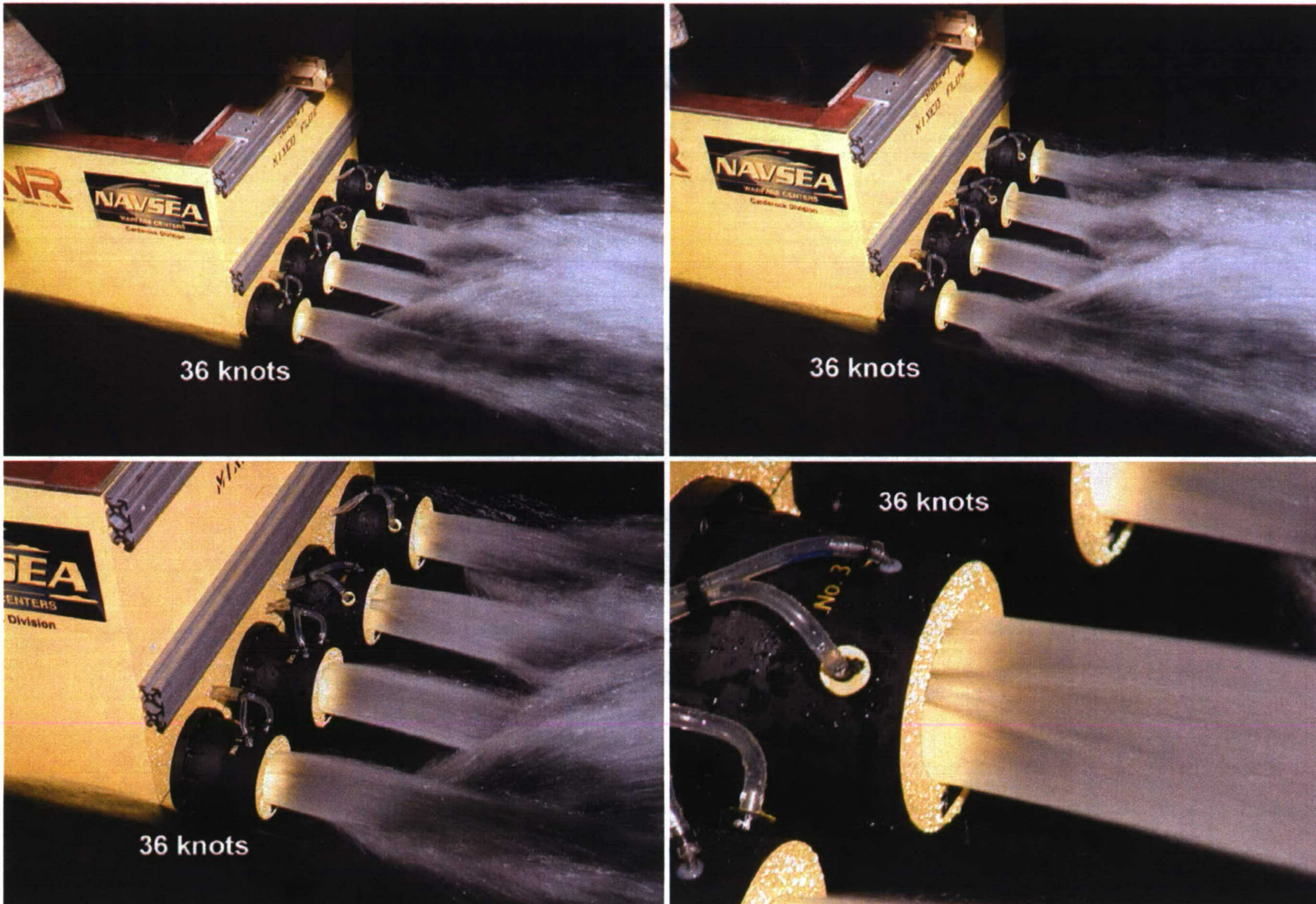


Fig B5. MxWJ Powering test underway (June 2007) – continued

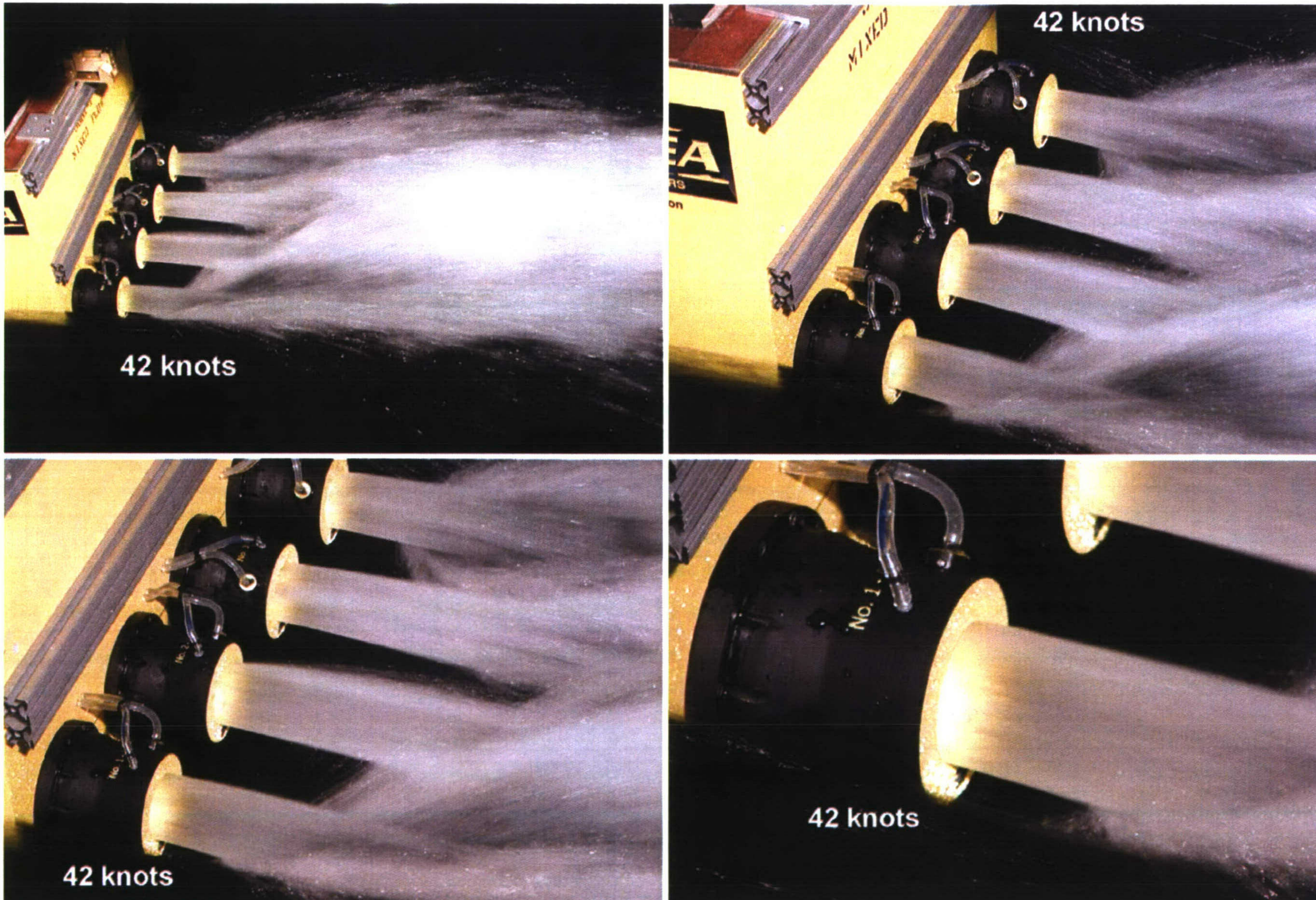


Fig B5. MxWJ Powering test underway (June 2007) – continued

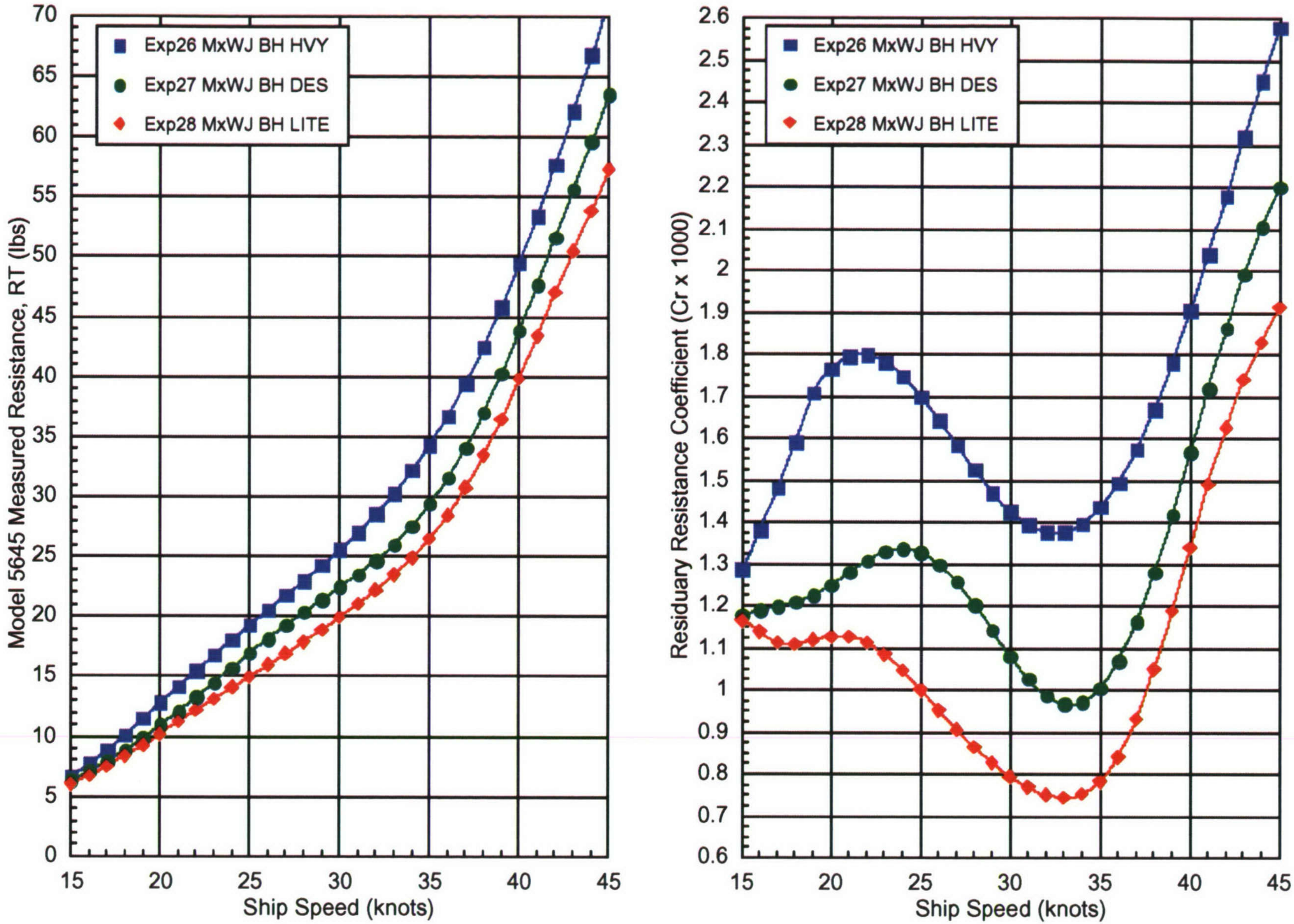
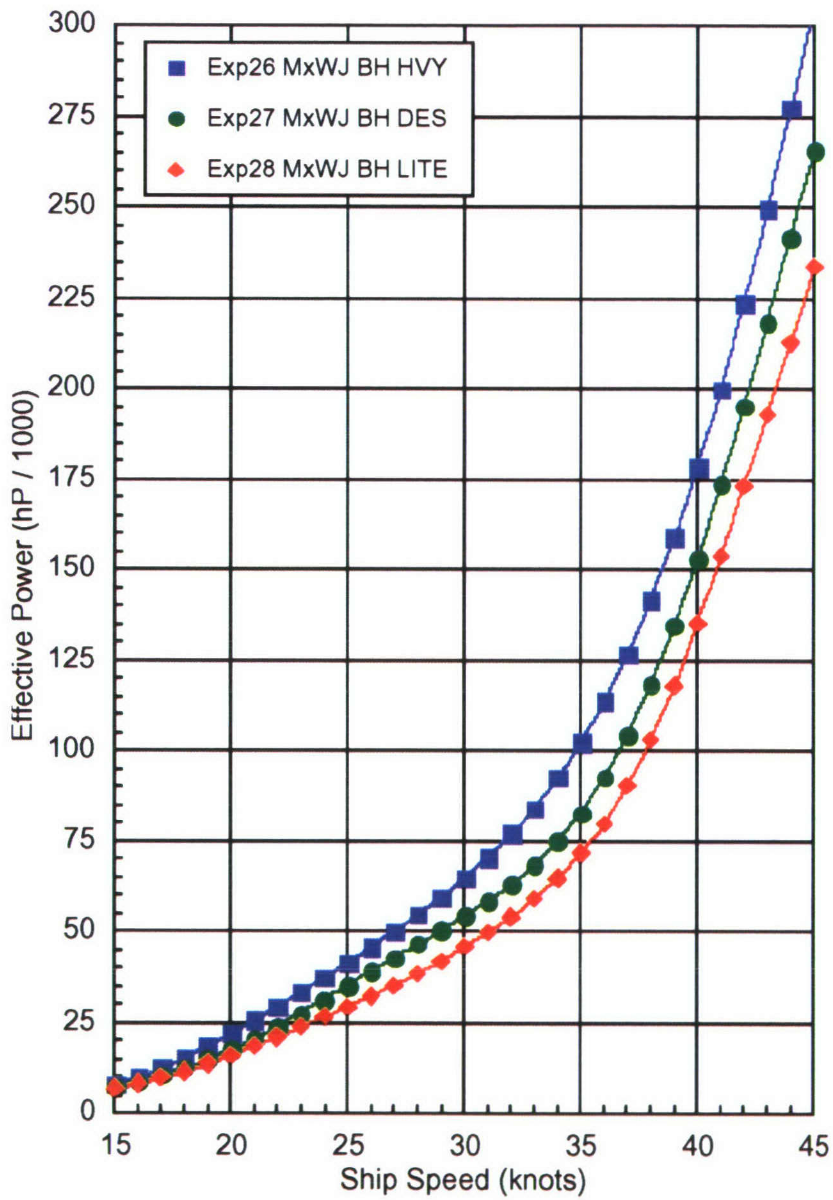


Fig B6. MxWJ bare hull resistance comparisons at three displacements



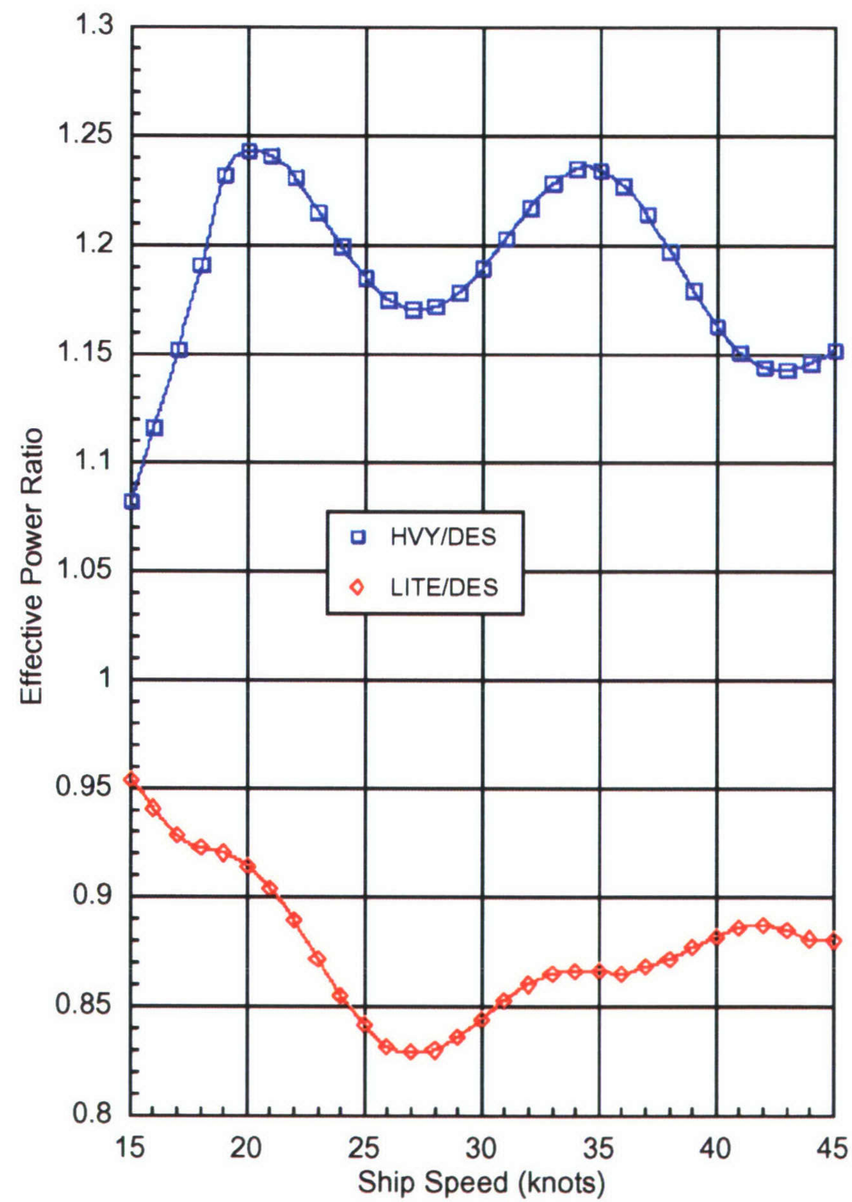


Fig B6. MxWJ bare hull resistance comparisons at three displacements - continued

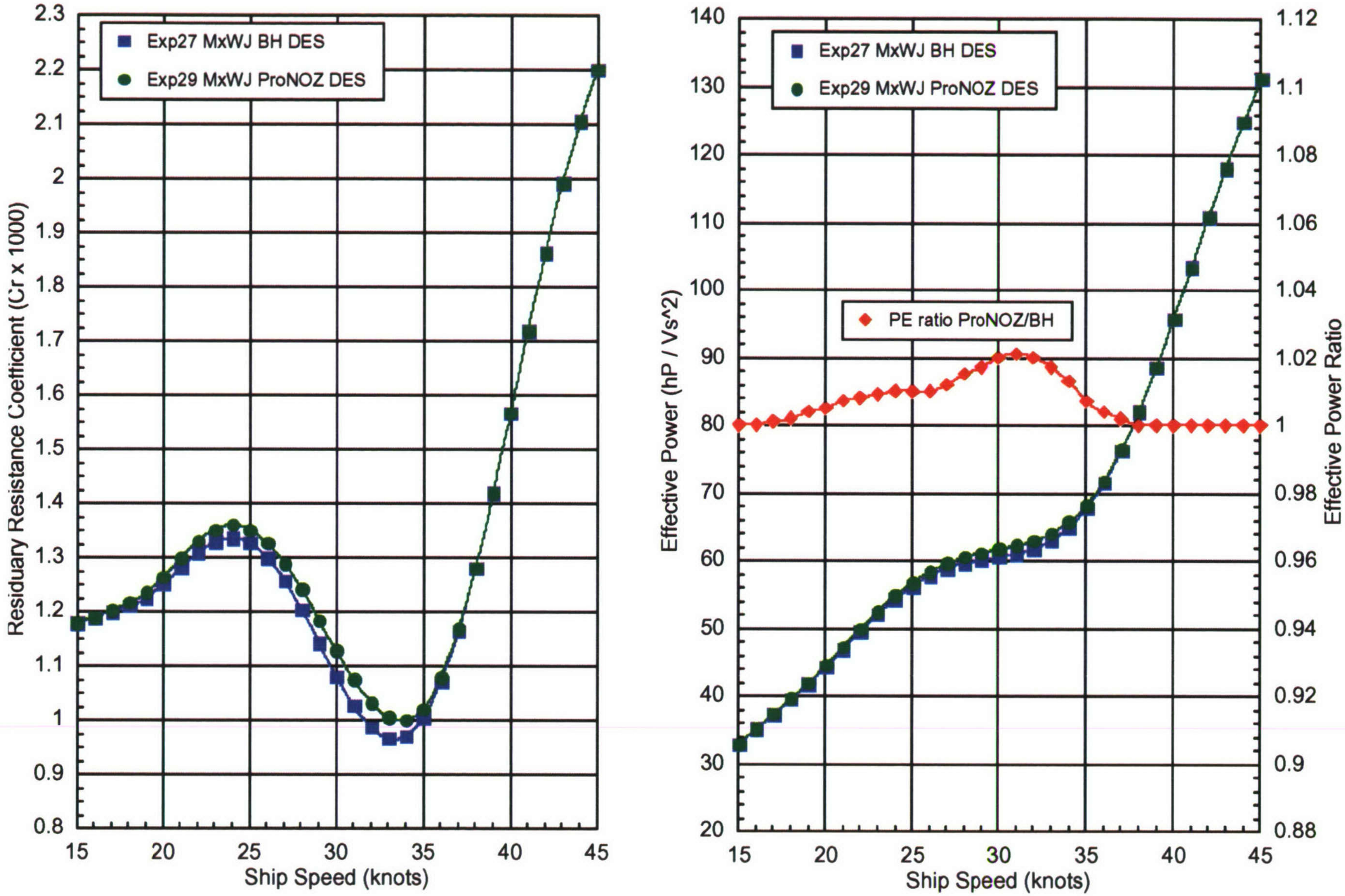


Fig B7. MxWJ resistance comparison, propulsion nozzles installed versus bare hull

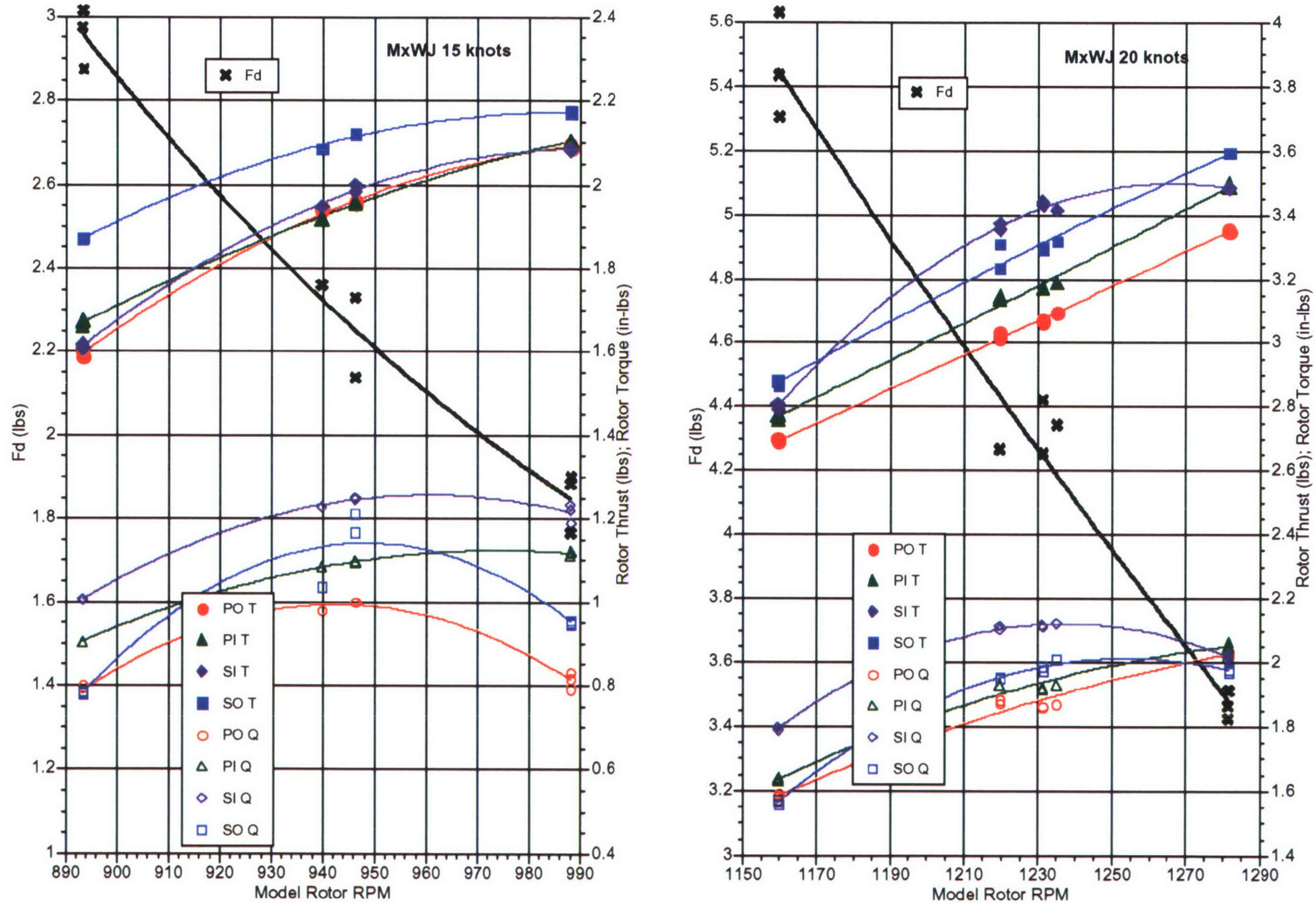


Fig B8. MxWJ over- and under-propelled data, model-scale rotor forces

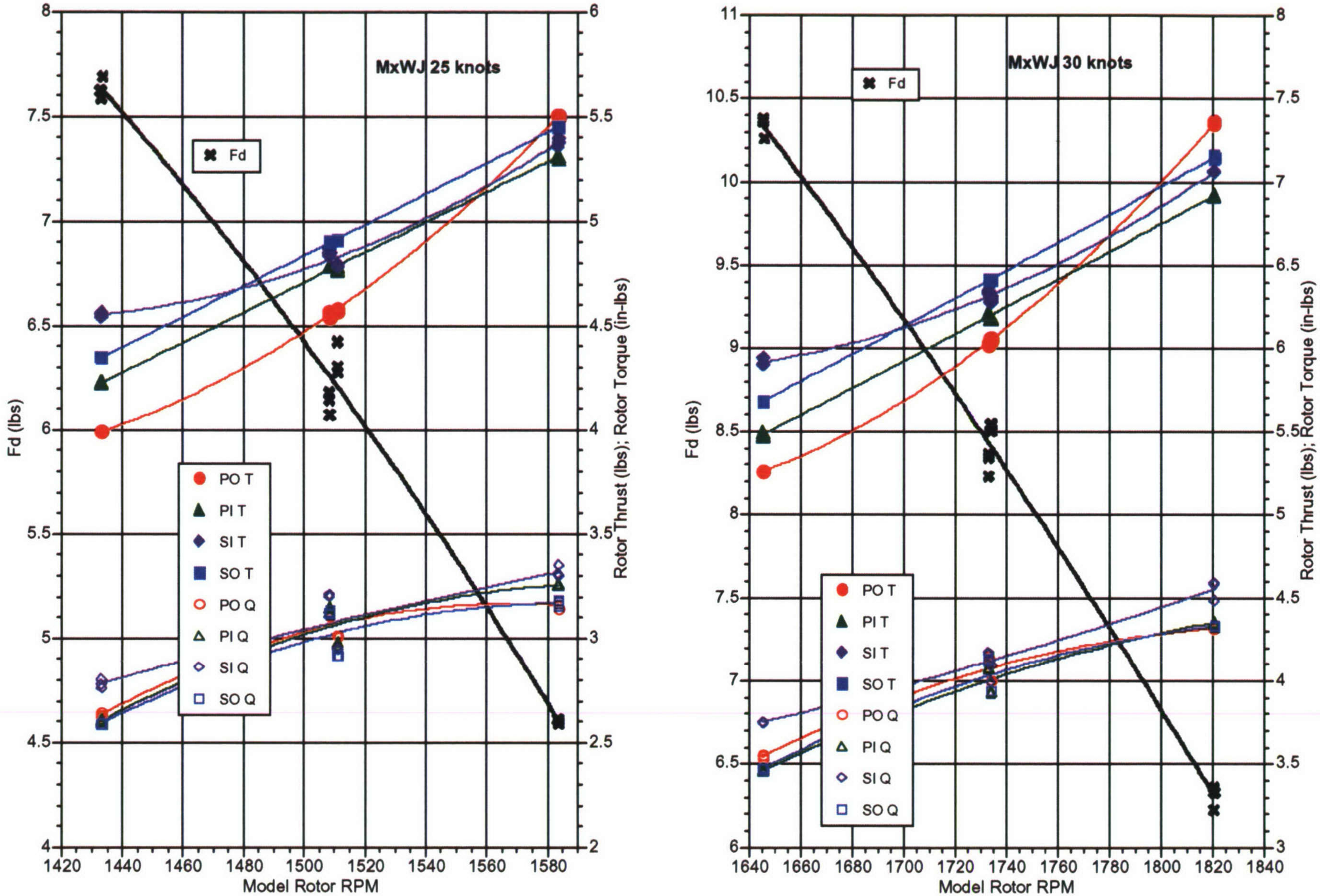


Fig B8. MxWJ over- and under-propelled data, model-scale rotor forces - continued

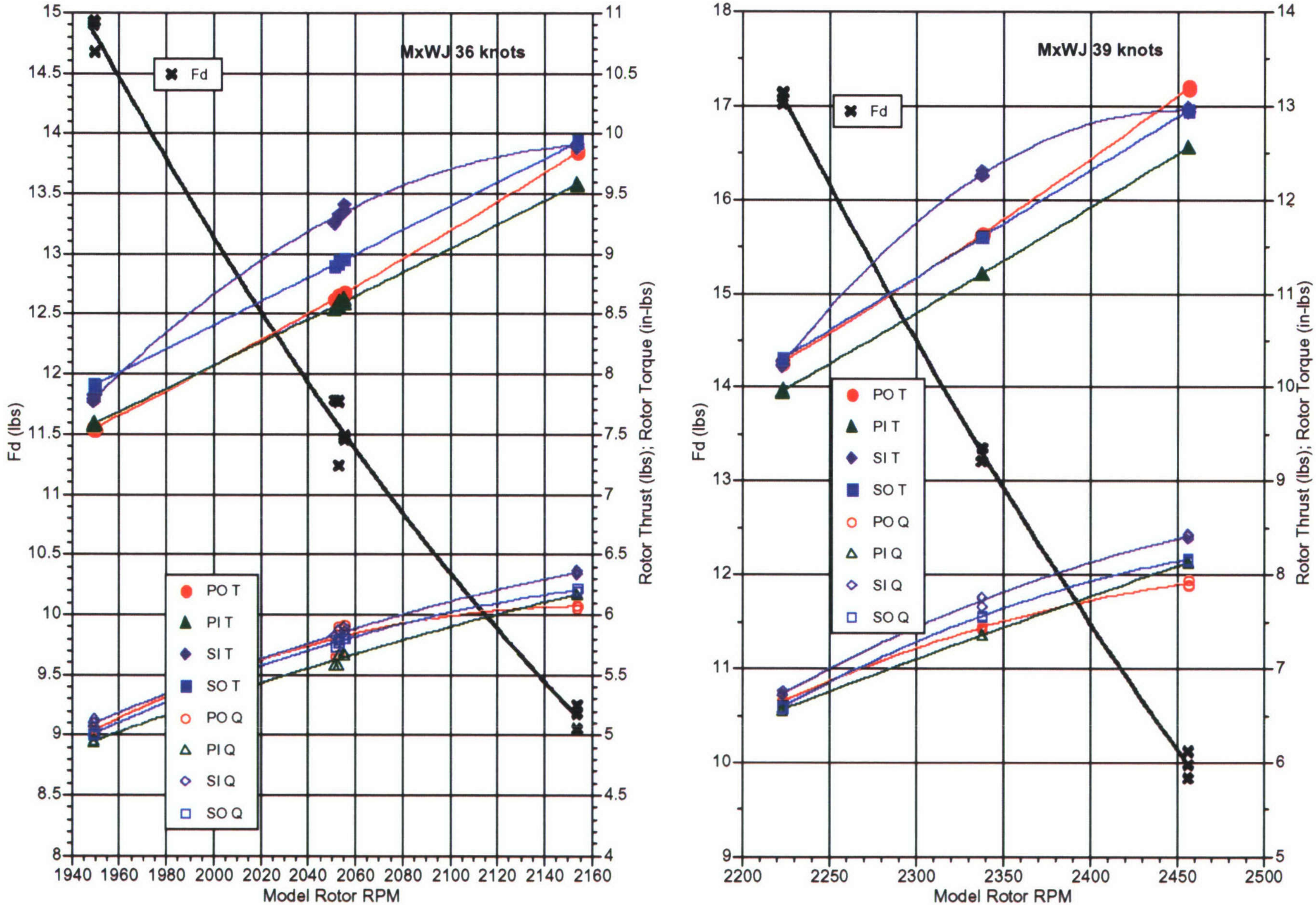


Fig B8. MxWJ over- and under-propelled data, model-scale rotor forces - continued

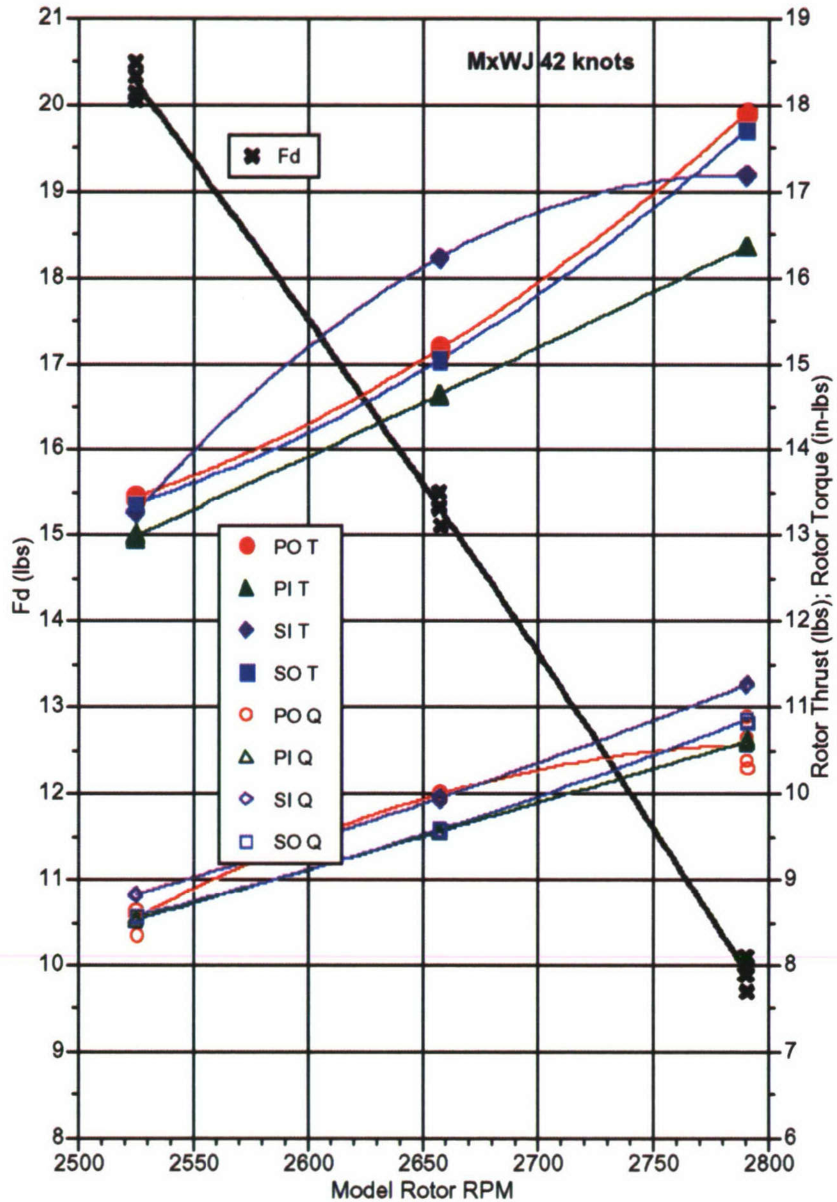


Fig B8. MxWJ over- and under-propelled data, model-scale rotor forces - continued

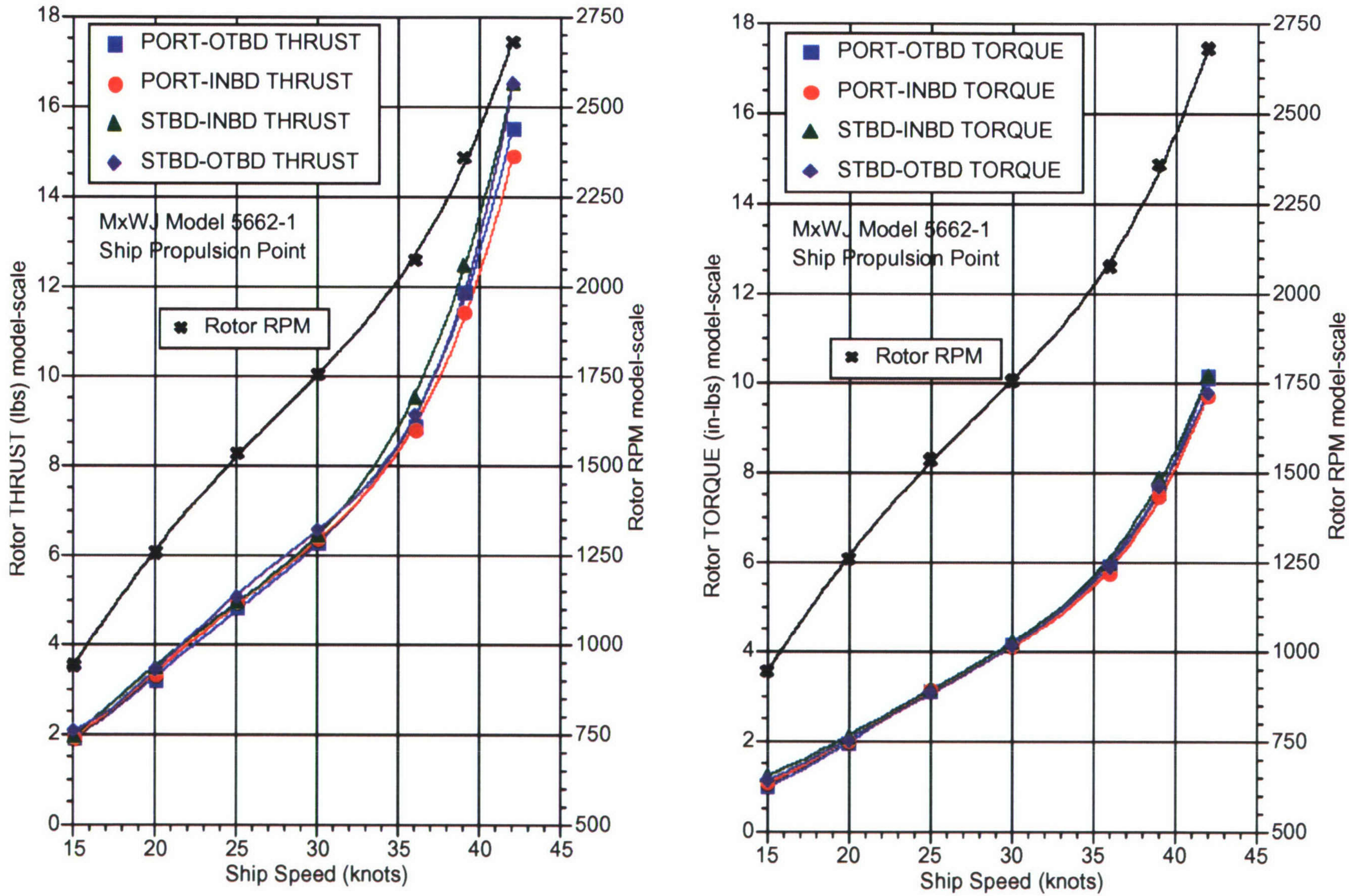


Fig B9. MxWJ model-scale rotor forces at ship propulsion point

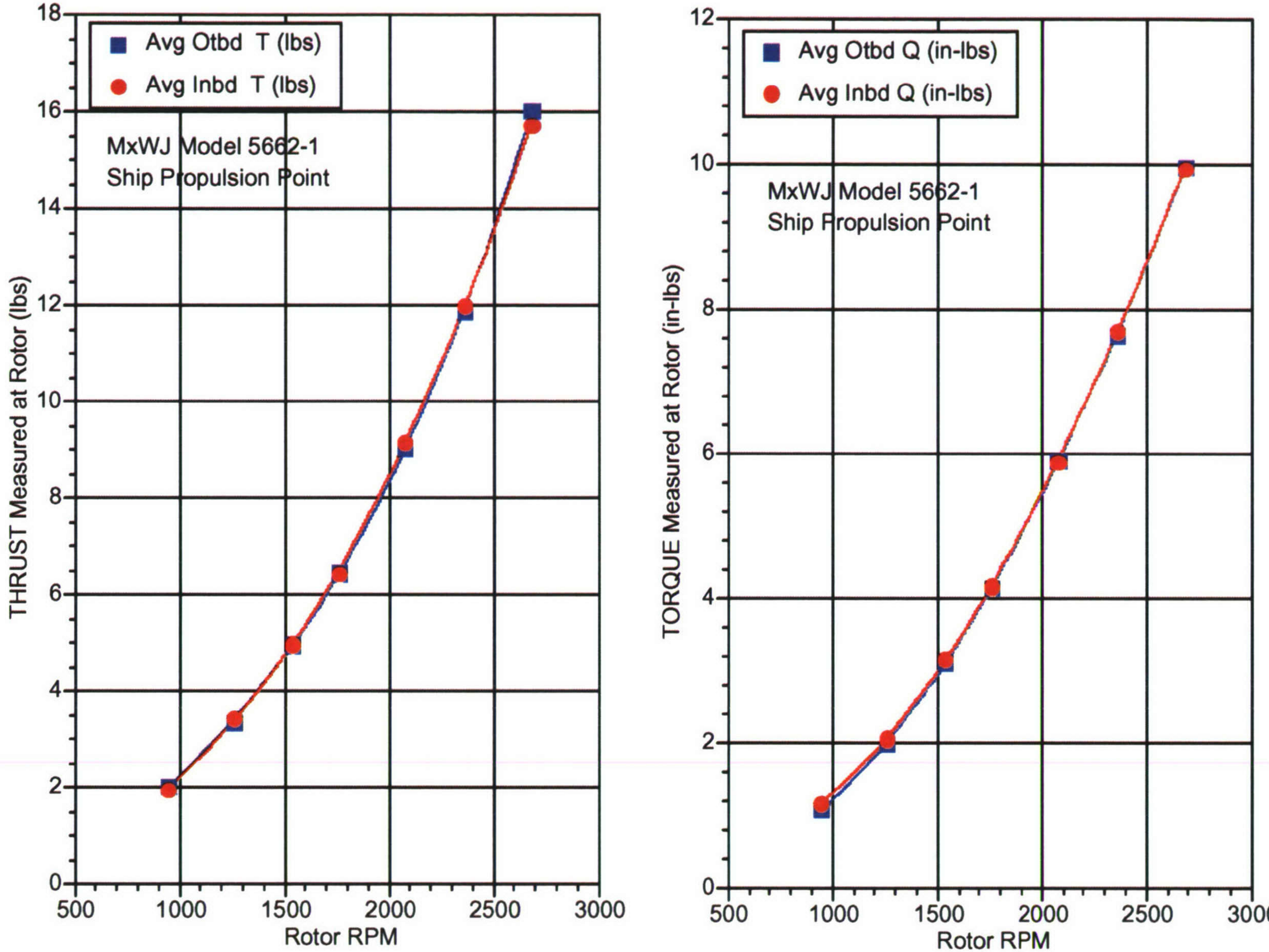


Fig B9. MxWJ model-scale rotor forces at ship propulsion point - continued

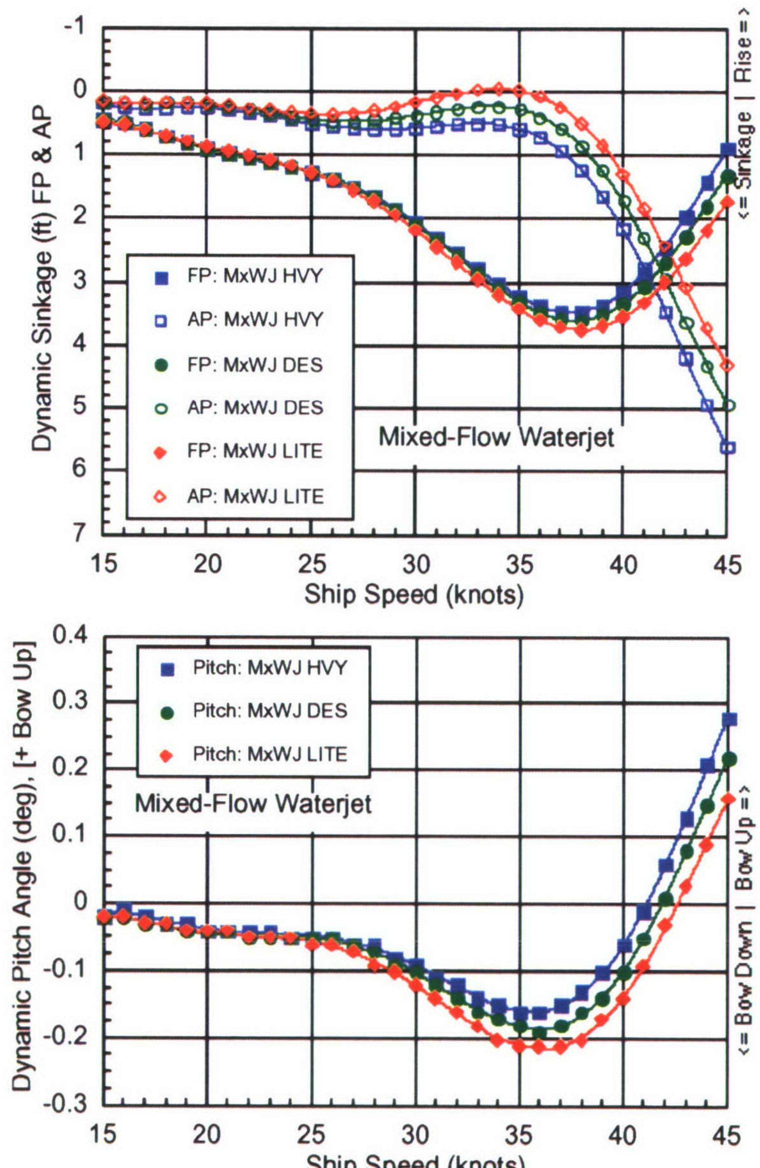


Fig B10. MxWJ dynamic sinkage and pitch, bare hull, three displacements

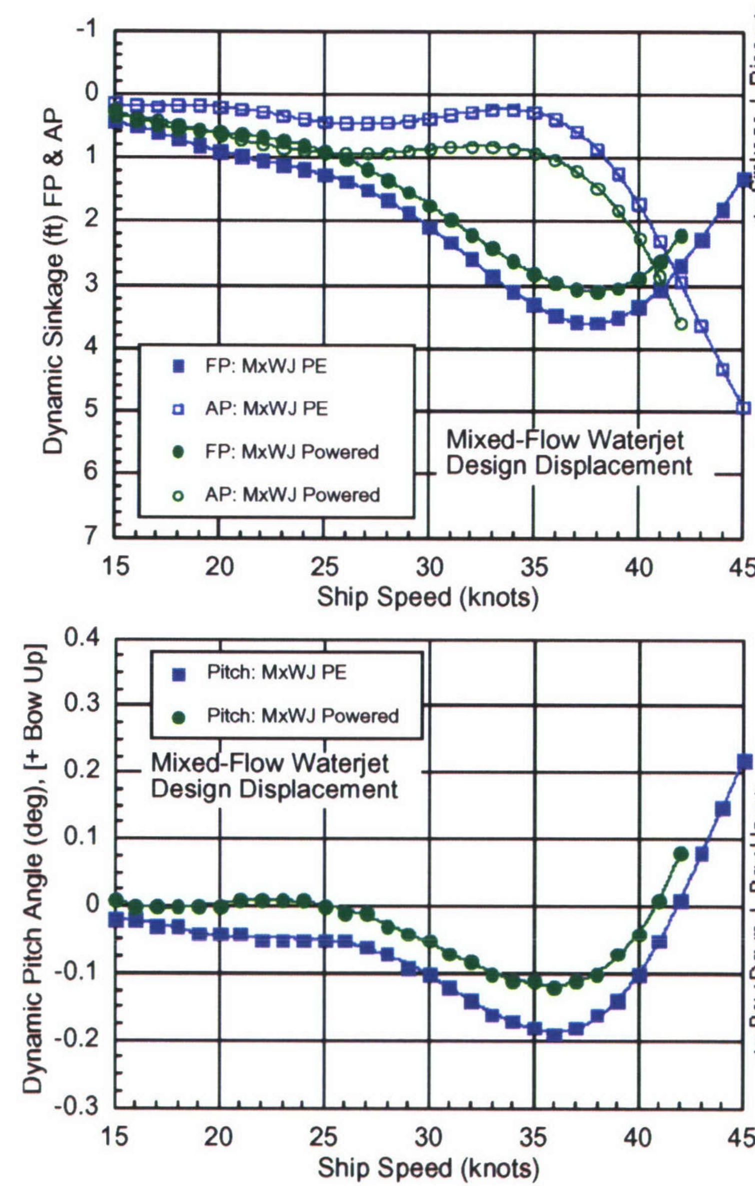


Fig B11. MxWJ dynamic sinkage and pitch, powered vs. unpowered, design displacement

Table B1. Test Agenda, MxWJ Model 5662-1, R&P tests with propulsion nozzles

Day	Date	Model	Test #	Objective	Req. Hours
				Continued from Previous Week's Testing Agenda on AxWJ Model 5662.	
Tue	5/22	MxWJ 5662-1		Half bow installed on MxWJ Model 5662-1. Dynamometers, drive train, nozzles, dummy hub shafts, pressure taps, pressure lines & manifolds and all instrumentation installed in MxWJ.	9
Wed	5/23		-	Inlets covered, transom plate installed.	1
			-	Model ballasted to Three displacements (HVY, DES, LITE).	4
			-	Model installed on Carriage 2. PE&PD measurement system Installation, Check-out & Troubleshooting.	3
			25	Model Alignment. Block Gage core malfunction.	5
Thr	5/24			Block Gage core replacement, calibration, reinstallation. Model alignment check.	
			26	HVY Bare Hull EHP Test, 15-45 kts.	3
			27	DES Bare Hull EHP Test, 15-45 kts.	3
Fri	5/25		28	LITE Bare Hull EHP Test, 15-45 kts.	3
			-	Model to Dry-dock. Re-ballasted to DES, transom plate removed, dummy hubs & shafts installed. Four Nozzles installed (with Plugs).	6
Week 3		(5) 9-hour days			
Mon	5/28	-	-	Holiday	-
Tue	5/29	MxWJ 5662-1	-	Sta 1 Pitot Tubes installation, pressure measurement system installation. Model reinstalled on carriage, check-out & troubleshooting.	9
Wed	5/30		29	DES EHP Test w/Nozzles, 7 (PD) speeds. Sta 1 pitot measurements.	4
			-	Nozzle plugs removed, Inlets opened (model waterborne).	2
			30	No Loads Conducted, RPMs: 800, 1200, 1600, 2000, 2400, 2800. Transom submerged manually (120lbs).	1
			-	Rotors installed, Nozzles installed with Kiel Probes (waterborne). Pressure system reconfiguration.	2
Thur	5/31	MxWJ 5662-1	31	Bollards Conducted, RPMs 1000, 1500, 1750, 2000, 2500, 2800, NO Blocking Board. All 4 jets simultaneously.	1
			32	DES Powering Test, 7 speeds. Kiel probes in Nozzles. Pressure measurements. 3 powering points for all speeds (Fd and over/under +/- 5% RPM).	5
			-	Blocking Board installed.	~
			33	Bollards Conducted, 2 methods. All 4 jets simultaneously, and each jet individually.	4
Fri	6/1		-	Blocking Board removed. Special Flow fixture over Kiel prob Nozzle installed with flow rate hardware and piping. Capture tank & scale into dry-dock.	5
			34	Height adjustments of capture tank to equate Keil probe measurements to that of dynamic running conditions.	4
Week 4		(5) 12-hour days			
Mon	6/4	MxWJ 5662-1	35	Kiel probe and Flow Rate measurements into capture tank for various rotor RPMs on each jet individually.	14
Tue	6/5		-	Model to dry-dock. Pressure measurement system removed from model and carriage. Two adjustable-height tow posts installed.	4
			-	LDV Equipment installed on carriage. LDV Nozzle and Probes installed on Stbd Inbd Jet (#3). Model installed on carriage with fixed-height posts. LDV adjustments, check-out, troubleshooting. Blocking Board installed.	30
Wed	6/6		-		
Thur	6/7		-		
Fri	6/8		-		
			36	LDV Bollards conducted on Stbd Inbd Jet (#3).	2
			37	LDV flow measurements on Stbd Inbd Jet (#3) conducted at dynamic sinkage & trim, DES power RPM, 6 speeds.	6

Table B1. Test Agenda, MxWJ Model 5662-1, R&P tests with propulsion nozzles - continued

Day	Date	Model	Test #	Objective	Req. Hours
Week 5		(5) 12-hour days			
Mon	6/11	MxWJ 5662-1	37	LDV on Stbd Inbd Jet (#3) continued	12
Tue	6/12		-	Flow rate hardware and piping installed on Stbd Inbd Jet (#3). Capture tank, scale, etc. moved into dry-dock.	3
			38	LDV and Flow Rate measurements into capture tank for Stbd Inbd Jet (#3)	3
			-	LDV Nozzle and Probes installed on Stbd Outbd Jet (#1).	3
			39	LDV Bollards conducted on Stbd Outbd Jet (#1).	3
Wed	6/13		40	LDV flow measurements on Stbd Outbd Jet (#1) conducted at dynamic sinkage & trim, DES power RPM, 7 speeds.	6
Thur	6/14		-	Flow rate hardware and piping installed on Stbd Inbd Jet (#1). Capture tank, scale, etc. moved into dry-dock.	3
			41	LDV and Flow Rate measurements into capture tank for Stbd Outbd Jet (#1).	3
Fri	6/15		-	De-Rig Model and Carriage	12

Test *Rotor RPMs (tbd)

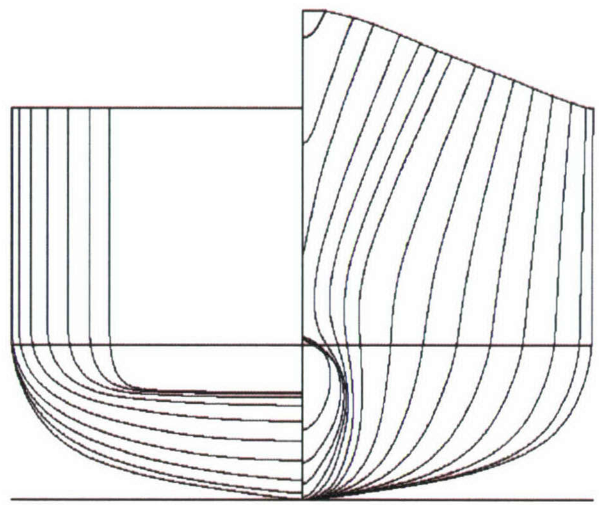
No Loads: 800, 1200, 1600, 2000, 2400, 2800

Bollards: 1000, 1500, 1750, 2000, 2500, 2800

Flow Rate: 1000, 1750, 2500

Table B2. MxWJ hydrostatic calculations, design displacement

JHSS Mixed Flow Waterjet Hull Gooseneck Bulb 06/10/2006



PRINCIPAL DIMENSIONS

LENGTH (LBP)	=	950.51 ft	(289.71 m)
LENGTH (LWL)	=	980.20 ft	(298.77 m)
BEAM (B_X)	=	104.75 ft	(31.93 m)
DRAFT (T_X)	=	27.83 ft	(8.48 m)
TRIM (+Bow)	=	0.00 ft	(0.00 m)
DISPLACEMENT	=	36491.0 T	(37075. t)
WETTED SURFACE	=	97372 sqft	(9046. sqm)

NONDIMENSIONAL COEFFICIENTS

C_B	= 0.447	C_{VP}	= 0.637	L_E/LWL	= 0.530
C_P	= 0.560	C_{VPF}	= 0.802	L_P/LWL	= 0.000
C_{PF}	= 0.497	C_{VPA}	= 0.860	L_R/LWL	= 0.470
C_{PA}	= 0.635	C_S	= 2.753	FB/LWL	= 0.502
C_{PE}	= 0.520	LWL/B_X	= 9.358	FF/LWL	= 0.567
C_{PR}	= 0.605	B_X/T_X	= 3.764	$100C_\nabla$	= 0.136
C_X	= 0.797	A_T/A_X	= 0.237	$\Delta/(.01LWL)^3$	= 38.7
C_{WP}	= 0.701	B_T/B_X	= 0.659	i_E	= 3.80
C_{WPF}	= 0.494	T_T/T_X	= 0.302	i_R	= 4.46
C_{WPA}	= 0.924	A_B/A_X	= 0.116	i_B	= 0.85

MODEL SCALE DATA

SCALE RATIO	=	34.121	
LENGTH (LBP)	=	27.86 ft	(8.49 m)
LENGTH (LWL)	=	28.73 ft	(8.76 m)
BEAM (B_X)	=	3.07 ft	(0.94 m)
DRAFT (T_X)	=	0.82 ft	(0.25 m)
DISPLACEMENT	=	2001.1 lbs	(0.91 t)
WETTED SURFACE	=	83.64 sqft	(7.77 sqm)

Table B3. MxWJ ship/model test parameters, three displacements

Mixed-Flow Waterjet Gooseneck Bulb (GB)	Design (DES) 36491 tons		Heavy (HVY) +10% 40140 tons		Light (LITE) -10% 32841 tons	
Model 5662-1	SHIP	MODEL	SHIP	MODEL		
MODEL SCALE RATIO	-	34.121	-	34.121	-	34.121
LOA (ft)	977.5	28.648	977.5	28.648	977.5	28.648
LBP (ft)	950.5	27.857	950.5	27.857	950.5	27.857
LWL (ft)	980.2	28.727	949.4	27.825	981.9	28.777
WET SURF HULL(sq ft)	97372	83.635	101083	86.823	93620	80.413
WET SURF APP(sq ft)	0	0.000	0	0.000	0	0.000
TOTAL WET SURF(sq ft)	97372	83.635	101083	86.823	93620	80.413
DISPLACEMENT (ton, lbs)	36491	2000	40140	2200	32841	1800
BOW DRAFT @FP (ft)	27.83	0.816	29.60	0.868	26.05	0.763
STERN DRAFT @AP (ft)	27.83	0.816	29.60	0.868	26.05	0.763
SHIP TRIM (+ft bow up)	0.00	0.000	0.00	0.000	0.00	0.000
TRIM ANGLE (degrees)	0.00		0.00		0.00	
BEAM (ft)	104.9	3.074	105.1	3.079	104.5	3.064
TEMP (F)	59	70	59	70	59	70
RHO	1.9905	1.9362	1.9905	1.9362	1.9905	1.9362
NU	1.2817	1.0552	1.2817	1.0552	1.2817	1.0552
Bow Deck/Keel (ft)	71.6	2.098	71.6	2.098	71.6	2.098
Pos of Hook fwd of FP (ft)	42.7	1.250	42.7	1.250	42.7	1.250
Stern Deck/Keel (ft)	70.9	2.077	70.9	2.077	70.9	2.077
Pos of Hook aft of AP (ft)	11.4	0.333	11.4	0.333	11.4	0.333
BOW HOOK SETTING (ft)		1.282		1.230		1.334
Hook if at FP (ft)	-	1.282	-	1.230	-	1.334
Hook if at AP (ft)	-	1.261	-	1.209	-	1.313
STERN HOOK SETTING (ft)		1.261		1.209		1.313
ROTOR DIA (ft, in)	9.91	3.485	9.91	3.485	9.91	3.485
NUMBER of BLADES	7	7	7	7	7	7
ROTOR ROTATION	INBD	INBD	INBD	INBD	INBD	INBD
SPEED RANGE, min (kts)	15.0	2.57	15.0	2.57	15.0	2.57
Design Speed (kts)	36.0	6.16	36.0	6.16	36.0	6.16
max (kts)	45.0	7.70	45.0	7.70	45.0	7.70
MODEL DISP desired (lbs)		2000		2200		1800
DISP actual (ton, lbs)	36485	2000	40134	2200	32837	1800
MODEL WEIGHT* (lbs)	-	1310	-	1310	-	1310
Floating Platform (lbs)	-	45	-	45	-	45
BALLAST required (lbs)	-	645	-	845	-	445
delta DISP (ton, lbs)			+ 3649	+200 +10.0%	-3649	-200 -10.0%
APPENDAGES, ws (sqft)	0.0	0.000	0.0	0.000	0.0	0.000
none	0.0	0.000	0.0	0.000	0.0	0.000

Table B4. MxWJ bare hull resistance prediction, DES displacement

JHSS MxWJ GB Exp27 BH DES (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	980.2	ft	28.727	ft
S (no Skeg)	97372	ft^2	83.635	ft^2
WT	36491	LT	2000.6	lbs
RHO	1.9905	$(lbf{*}sec^2)/ft^4$	1.9365	$(lbf{*}sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	6027.9	4495.0	3310.6	2468.7	0.133	0.447	1.169
15.0	7409.0	5524.9	4038.4	3011.4	0.143	0.479	1.179
16.0	8989.4	6703.4	4863.7	3626.8	0.152	0.511	1.189
17.0	10783.3	8041.1	5792.0	4319.1	0.162	0.543	1.199
18.0	12805.4	9549.0	6829.2	5092.5	0.171	0.575	1.210
19.0	15098.5	11259.0	7980.8	5951.3	0.181	0.607	1.225
20.0	17725.5	13217.9	9252.5	6899.6	0.190	0.639	1.250
21.0	20693.5	15431.2	10650.0	7941.7	0.200	0.671	1.280
22.0	23980.3	17882.1	12178.7	9081.7	0.209	0.703	1.308
23.0	27535.9	20533.6	13844.3	10323.7	0.219	0.735	1.328
24.0	31289.1	23332.3	15652.2	11671.8	0.228	0.767	1.335
25.0	35158.0	26217.3	17607.9	13130.2	0.238	0.799	1.326
26.0	39064.4	29130.3	19717.0	14702.9	0.247	0.830	1.299
27.0	42949.5	32027.4	21984.7	16394.0	0.257	0.862	1.257
28.0	46790.5	34891.7	24416.7	18207.5	0.266	0.894	1.203
29.0	50616.0	37744.4	27018.3	20147.5	0.276	0.926	1.142
30.0	54517.5	40653.7	29794.8	22218.0	0.285	0.958	1.081
31.0	58656.2	43739.9	32751.6	24422.9	0.295	0.990	1.026
32.0	63263.0	47175.2	35894.2	26766.3	0.304	1.022	0.986
33.0	68630.1	51177.5	39227.7	29252.1	0.314	1.054	0.966
34.0	75093.7	55997.4	42757.6	31884.3	0.323	1.086	0.971
35.0	83007.5	61898.7	46489.1	34666.9	0.333	1.118	1.005
36.0	92709.1	69133.1	50427.5	37603.8	0.342	1.150	1.070
37.0	104479.5	77910.4	54578.0	40698.8	0.352	1.182	1.163
38.0	118502.1	88367.0	58946.0	43956.0	0.361	1.214	1.281
39.0	134823.5	100537.9	63536.6	47379.3	0.371	1.246	1.419
40.0	153327.1	114336.0	68355.2	50972.4	0.380	1.278	1.567
41.0	173725.2	129546.9	73406.8	54739.4	0.390	1.310	1.718
42.0	195586.3	145848.7	78696.7	58684.1	0.399	1.342	1.862
43.0	218408.2	162867.0	84230.0	62810.3	0.409	1.373	1.992
44.0	241892.1	180378.9	90012.0	67121.9	0.418	1.405	2.105
45.0	265912.9	198291.2	96047.8	71622.8	0.428	1.437	2.200

Table B5. MxWJ bare hull resistance prediction, HVY displacement

JHSS MxWJ GB Exp26 BH HVY (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	949.4	ft	27.825	ft
S (no Skeg)	101083	ft^2	86.823	ft^2
WT	40140	LT	2200.7	lbs
RHO	1.9905	$(lbf*sec^2)/ft^4$	1.9365	$(lbf*sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	6344.5	4731.1	3449.9	2572.6	0.135	0.454	1.199
15.0	8024.4	5983.8	4208.3	3138.1	0.145	0.487	1.286
16.0	10037.7	7485.1	5068.2	3779.4	0.155	0.519	1.380
17.0	12430.7	9269.6	6035.5	4500.7	0.164	0.552	1.480
18.0	15270.2	11387.0	7116.2	5306.5	0.174	0.584	1.590
19.0	18619.8	13884.8	8316.1	6201.3	0.183	0.617	1.708
20.0	22059.1	16449.4	9641.2	7189.4	0.193	0.649	1.765
21.0	25711.0	19172.7	11097.2	8275.2	0.203	0.682	1.794
22.0	29533.0	22022.8	12690.0	9462.9	0.212	0.714	1.799
23.0	33487.4	24971.6	14425.3	10757.0	0.222	0.746	1.781
24.0	37546.0	27998.1	16309.0	12161.6	0.232	0.779	1.747
25.0	41695.4	31092.3	18346.6	13681.1	0.241	0.811	1.699
26.0	45941.4	34258.5	20544.0	15319.6	0.251	0.844	1.643
27.0	50313.5	37518.7	22906.7	17081.5	0.261	0.876	1.583
28.0	54867.5	40914.7	25440.4	18970.9	0.270	0.909	1.524
29.0	59688.5	44509.7	28150.9	20992.1	0.280	0.941	1.470
30.0	64891.5	48389.6	31043.5	23149.2	0.290	0.974	1.425
31.0	70620.8	52661.9	34124.1	25446.3	0.299	1.006	1.393
32.0	77048.0	57454.7	37398.1	27887.7	0.309	1.039	1.376
33.0	84368.2	62913.4	40871.0	30477.5	0.319	1.071	1.376
34.0	92794.1	69196.6	44548.5	33219.8	0.328	1.103	1.396
35.0	102548.6	76470.5	48436.0	36118.7	0.338	1.136	1.435
36.0	113855.3	84901.9	52539.0	39178.3	0.348	1.168	1.494
37.0	126927.5	94649.8	56863.0	42402.8	0.357	1.201	1.573
38.0	141956.0	105856.6	61413.6	45796.1	0.367	1.233	1.669
39.0	159095.3	118637.3	66196.0	49362.4	0.377	1.266	1.781
40.0	178448.7	133069.2	71215.9	53105.7	0.386	1.298	1.905
41.0	200054.4	149180.5	76478.5	57030.0	0.396	1.331	2.039
42.0	223869.9	166939.7	81989.3	61139.4	0.406	1.363	2.178
43.0	249759.1	186245.4	87753.8	65438.0	0.415	1.396	2.317
44.0	277480.3	206917.1	93777.2	69929.7	0.425	1.428	2.452
45.0	306677.0	228689.0	100065.1	74618.5	0.435	1.460	2.578

Table B6. MxWJ bare hull resistance prediction, LITE displacement

JHSS MxWJ GB Exp28 BH LITE (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	981.9	ft	28.777	ft
S (no Skeg)	93620	ft^2	80.413	ft^2
WT	32841	LT	1800.5	lbs
RHO	1.9905	$(lbf*sec^2)/ft^4$	1.9365	$(lbf*sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	5814.8	4336.1	3182.3	2373.1	0.133	0.447	1.178
15.0	7079.1	5278.9	3882.0	2894.8	0.142	0.479	1.163
16.0	8464.9	6312.3	4675.3	3486.4	0.152	0.511	1.136
17.0	10017.1	7469.7	5567.7	4151.8	0.161	0.543	1.112
18.0	11828.6	8820.6	6564.7	4895.3	0.171	0.574	1.108
19.0	13909.5	10372.3	7671.7	5720.8	0.180	0.606	1.117
20.0	16226.6	12100.2	8894.2	6632.4	0.190	0.638	1.125
21.0	18723.5	13962.1	10237.6	7634.1	0.199	0.670	1.125
22.0	21341.7	15914.5	11707.1	8730.0	0.209	0.702	1.111
23.0	24038.3	17925.3	13308.2	9923.9	0.218	0.734	1.083
24.0	26796.0	19981.8	15046.1	11219.8	0.228	0.766	1.044
25.0	29624.9	22091.3	16926.1	12621.8	0.237	0.798	0.998
26.0	32555.8	24276.9	18953.4	14133.6	0.247	0.830	0.950
27.0	35629.6	26569.0	21133.4	15759.2	0.256	0.862	0.904
28.0	38886.5	28997.7	23471.2	17502.5	0.266	0.894	0.862
29.0	42360.9	31588.5	25972.1	19367.4	0.275	0.925	0.825
30.0	46084.9	34365.5	28641.1	21357.6	0.285	0.957	0.793
31.0	50103.6	37362.3	31483.4	23477.2	0.294	0.989	0.767
32.0	54500.6	40641.1	34504.3	25729.9	0.304	1.021	0.749
33.0	59428.0	44315.5	37708.8	28119.4	0.313	1.053	0.742
34.0	65131.3	48568.4	41102.0	30649.7	0.323	1.085	0.751
35.0	71956.4	53657.9	44689.0	33324.6	0.332	1.117	0.781
36.0	80323.4	59897.2	48474.9	36147.7	0.342	1.149	0.838
37.0	90782.1	67696.2	52464.8	39123.0	0.351	1.181	0.929
38.0	103451.8	77144.0	56663.6	42254.1	0.361	1.213	1.047
39.0	118399.0	88290.2	61076.5	45544.8	0.370	1.245	1.186
40.0	135408.9	100974.4	65708.5	48998.8	0.380	1.277	1.337
41.0	154082.5	114899.4	70564.5	52620.0	0.389	1.308	1.488
42.0	173672.5	129507.6	75649.6	56411.9	0.399	1.340	1.624
43.0	193487.9	144283.9	80968.8	60378.4	0.408	1.372	1.737
44.0	213332.0	159081.7	86526.9	64523.1	0.418	1.404	1.828
45.0	234217.9	174656.3	92329.0	68849.8	0.427	1.436	1.912

Table B7. MxWJ resistance prediction with propulsion nozzles installed, DES displacement

JHSS MxWJ GB Exp29 BH PropNozzles DES (PE from RT input with WS no skeg)

	SHIP		MODEL	
LAMBDA			34.121	
LWL	980.2	ft	28.727	ft
S (no Skeg)	97372	ft^2	83.635	ft^2
WT	36491	LT	2000.6	lbs
RHO	1.9905	$(lbf*sec^2)/ft^4$	1.9365	$(lbf*sec^2)/ft^4$
NU	1.2817E-05	ft^2/sec	1.0692E-05	ft^2/sec
Ca			0.0000	

Vs	PE		FRICTIONAL POWER		FN	V-L	1000CR
knots	HP	KW	HP	KW			
14.0	6027.9	4495.0	3310.6	2468.7	0.133	0.447	1.169
15.0	7409.0	5524.9	4038.4	3011.4	0.143	0.479	1.179
16.0	8989.4	6703.4	4863.7	3626.8	0.152	0.511	1.189
17.0	10793.5	8048.7	5792.0	4319.1	0.162	0.543	1.202
18.0	12836.1	9571.9	6829.2	5092.5	0.171	0.575	1.216
19.0	15156.7	11302.3	7980.8	5951.3	0.181	0.607	1.235
20.0	17819.5	13288.0	9252.5	6899.6	0.190	0.639	1.264
21.0	20833.5	15535.5	10650.0	7941.7	0.200	0.671	1.298
22.0	24177.5	18029.2	12178.7	9081.7	0.209	0.703	1.330
23.0	27771.8	20709.4	13844.3	10323.7	0.219	0.735	1.351
24.0	31587.4	23554.7	15652.2	11671.8	0.228	0.767	1.361
25.0	35493.4	26467.4	17607.9	13130.2	0.238	0.799	1.351
26.0	39474.4	29436.1	19717.0	14702.9	0.247	0.830	1.327
27.0	43477.6	32421.3	21984.7	16394.0	0.257	0.862	1.289
28.0	47504.9	35424.4	24416.7	18207.5	0.266	0.894	1.242
29.0	51471.5	38382.3	27018.3	20147.5	0.276	0.926	1.184
30.0	55588.9	41452.6	29794.8	22218.0	0.285	0.958	1.128
31.0	59883.9	44655.5	32751.6	24422.9	0.295	0.990	1.075
32.0	64542.1	48129.0	35894.2	26766.3	0.304	1.022	1.032
33.0	69818.7	52063.8	39227.7	29252.1	0.314	1.054	1.005
34.0	76050.3	56710.7	42757.6	31884.3	0.323	1.086	1.000
35.0	83550.3	62303.5	46489.1	34666.9	0.333	1.118	1.020
36.0	93068.5	69401.1	50427.5	37603.8	0.342	1.150	1.079
37.0	104682.3	78061.6	54578.0	40698.8	0.352	1.182	1.168
38.0	118483.1	88352.9	58946.0	43956.0	0.361	1.214	1.281
39.0	134832.4	100544.5	63536.6	47379.3	0.371	1.246	1.419
40.0	153332.2	114339.8	68355.2	50972.4	0.380	1.278	1.567
41.0	173716.8	129540.6	73406.8	54739.4	0.390	1.310	1.718
42.0	195588.3	145850.2	78696.7	58684.1	0.399	1.342	1.862
43.0	218399.3	162860.4	84230.0	62810.3	0.409	1.373	1.992
44.0	241892.1	180378.9	90012.0	67121.9	0.418	1.405	2.105
45.0	265912.9	198291.2	96047.8	71622.8	0.428	1.437	2.200

Table B8. MxWJ summary and comparisons of resistance predictions

MxWJ Model 5662 1	Exp27 BH DES	Exp26 BH HVY	Exp28 BH LITE	Displacement Effects HVY/DES	Displacement Effects LITE/DES	Exp29 Propulsion Nozzles DES	Exp29 Propulsion Nozzles NOZ/DES
Vs (kts)	PE (hP)	PE (hP)	PE (hP)	PE ratio	PE ratio	PE (hP)	PE ratio
14	6028	6344	5815	1.053	0.965	6028	1.0
15	7409	8024	7079	1.083	0.955	7409	1.0
16	8989	10038	8465	1.117	0.942	8989	1.0
17	10783	12431	10017	1.153	0.929	10793	1.001
18	12805	15270	11829	1.192	0.924	12836	1.002
19	15099	18620	13909	1.233	0.921	15157	1.004
20	17725	22059	16227	1.244	0.915	17820	1.005
21	20694	25711	18724	1.242	0.905	20833	1.007
22	23980	29533	21342	1.232	0.890	24178	1.008
23	27536	33487	24038	1.216	0.873	27772	1.009
24	31289	37546	26796	1.200	0.856	31587	1.010
25	35158	41695	29625	1.186	0.843	35493	1.010
26	39064	45941	32556	1.176	0.833	39474	1.010
27	42949	50313	35630	1.171	0.830	43478	1.012
28	46791	54867	38886	1.173	0.831	47505	1.015
29	50616	59689	42361	1.179	0.837	51472	1.017
30	54517	64891	46085	1.190	0.845	55589	1.020
31	58656	70621	50104	1.204	0.854	59884	1.021
32	63263	77048	54501	1.218	0.861	64542	1.020
33	68630	84368	59428	1.229	0.866	69819	1.017
34	75094	92794	65131	1.236	0.867	76050	1.013
35	83008	102549	71956	1.235	0.867	83550	1.007
36	92709	113855	80323	1.228	0.866	93068	1.004
37	104480	126927	90782	1.215	0.869	104682	1.002
38	118502	141956	103452	1.198	0.873	118483	1.0
39	134824	159095	118399	1.180	0.878	134832	1.0
40	153327	178449	135409	1.164	0.883	153332	1.0
41	173725	200054	154083	1.152	0.887	173717	1.0
42	195586	223870	173672	1.145	0.888	195588	1.0
43	218408	249759	193488	1.144	0.886	218399	1.0
44	241892	277480	213332	1.147	0.882	241892	1.0
45	265913	306677	234218	1.153	0.881	265913	1.0

Table B9. MxWJ over- and under-propelled data, model-scale rotor forces

MxWJ: 15 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	977.0	1.94	2.07	2.07	2.08	2.17	0.89	1.12	1.24	1.05
+2.5% RPM	953.8	2.17	2.00	1.99	2.02	2.14	0.99	1.11	1.26	1.14
Tested Fd	930.5	**2.44**	1.88	1.88	1.91	2.06	0.98	1.06	1.21	1.10
-2.5% RPM	907.2	2.75	1.72	1.75	1.74	1.95	0.89	0.97	1.10	0.94
-5% RPM	884.0	3.11	1.51	1.61	1.52	1.81	0.70	0.85	0.93	0.65

MxWJ: 20 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	1305.2	3.14	3.49	3.64	3.41	3.72	2.07	2.08	1.88	1.88
+2.5% RPM	1274.1	3.59	3.31	3.45	3.50	3.55	2.01	2.04	2.05	1.99
Tested Fd	1243.0	**4.06**	3.14	3.26	3.47	3.38	1.93	1.97	2.12	2.01
-2.5% RPM	1211.9	4.56	2.98	3.07	3.32	3.20	1.82	1.87	2.09	1.93
-5% RPM	1180.9	5.08	2.81	2.89	3.05	3.01	1.69	1.74	1.95	1.75

MxWJ: 25 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	1594.4	4.34	5.67	5.39	5.48	5.53	3.15	3.26	3.35	3.17
+2.5% RPM	1556.5	5.23	5.11	5.11	5.14	5.25	3.16	3.21	3.23	3.15
Tested Fd	1518.5	**6.05**	4.65	4.84	4.87	4.97	3.09	3.10	3.11	3.05
-2.5% RPM	1480.5	6.80	4.30	4.57	4.68	4.69	2.94	2.92	2.97	2.89
-5% RPM	1442.6	7.48	4.04	4.29	4.57	4.42	2.70	2.67	2.82	2.66

MxWJ: 30 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	1820.7	6.30	7.35	6.92	7.06	7.15	4.31	4.35	4.55	4.33
+2.5% RPM	1777.4	7.39	6.63	6.56	6.65	6.78	4.23	4.20	4.33	4.22
Tested Fd	1734.0	**8.41**	6.05	6.20	6.32	6.42	4.07	4.01	4.12	4.04
-2.5% RPM	1690.7	9.38	5.59	5.85	6.08	6.05	3.85	3.76	3.93	3.79
-5% RPM	1647.3	10.30	5.27	5.50	5.92	5.70	3.56	3.47	3.76	3.49

Table B9. MxWJ over- and under-propelled data, model-scale rotor forces - continued

MxWJ: 36 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	2153.6	9.16	9.86	9.58	9.91	9.93	6.08	6.17	6.36	6.21
+2.5% RPM	2102.3	10.29	9.23	9.07	9.72	9.42	6.01	5.91	6.12	6.03
Tested Fd	2051.0	**11.62**	8.63	8.57	9.31	8.91	5.81	5.62	5.83	5.77
-2.5% RPM	1999.7	13.14	8.07	8.07	8.66	8.41	5.49	5.30	5.49	5.43
-5% RPM	1948.5	14.86	7.55	7.58	7.79	7.90	5.04	4.95	5.10	5.01

MxWJ: 39 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	2450.2	10.14	13.12	12.50	12.96	12.89	7.90	8.10	8.39	8.15
+2.5% RPM	2391.8	11.71	12.33	11.82	12.77	12.22	7.70	7.72	8.09	7.89
Tested Fd	2333.5	**13.44**	11.59	11.16	12.23	11.56	7.42	7.33	7.70	7.54
-2.5% RPM	2275.2	15.31	10.88	10.52	11.34	10.89	7.06	6.93	7.23	7.08
-5% RPM	2216.8	17.33	10.20	9.90	10.10	10.24	6.61	6.53	6.68	6.53

MxWJ: 42 knots Ship Speed: Over & Under-Propelled Faired Rotor Forces										
			1	2	3	4	1	2	3	4
Values	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
As Tested	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
+5% RPM	2789.6	9.95	17.88	16.35	17.18	17.18	10.55	10.60	11.25	10.85
+2.5% RPM	2723.2	12.71	16.39	15.48	16.95	16.95	10.38	10.07	10.57	10.18
Tested Fd	2656.8	**15.35**	15.15	14.63	16.21	16.21	9.98	9.55	9.94	9.58
-2.5% RPM	2590.3	17.88	14.16	13.80	14.98	14.98	9.36	9.04	9.35	9.04
-5% RPM	2523.9	20.29	13.43	12.98	13.24	13.24	8.52	8.52	8.81	8.57

Table B10. MxWJ model-scale rotor forces at ship propulsion point

JHSS MxWJ Rotor Forces at Ship Propulsion Point										
Ship Speed (knots)	Rotor RPM	FD (lbs)	1 Port Out T (lbs)	2 Port In T (lbs)	3 Stbd In T (lbs)	4 Stbd Out T (lbs)	1 Port Out Q (in-lbs)	2 Port In Q (in-lbs)	3 Stbd In Q (in-lbs)	4 Stbd Out Q (in-lbs)
15	942.0	2.30	1.94	1.94	1.97	2.10	1.00	1.09	1.24	1.14
20	1258.0	3.83	3.23	3.35	3.50	3.47	1.97	2.01	2.10	2.01
25	1535.0	5.71	4.84	4.96	4.98	5.09	3.13	3.15	3.16	3.10
30	1755.0	7.92	6.31	6.37	6.47	6.59	4.16	4.11	4.22	4.13
36	2074.8	10.98	8.91	8.80	9.53	9.15	5.91	5.76	5.98	5.90
39	2358.8	12.67	11.91	11.45	12.50	11.84	7.55	7.50	7.88	7.70
42	2679.3	14.47	15.54	14.92	16.52	16.52	10.14	9.73	10.15	9.77

JHSS MxWJ Rotor Forces at Ship Propulsion Point					
Ship Speed (knots)	Rotor RPM	1&4 Avg Otbd T (lbs)	2&3 Avg Inbd T (lbs)	1&4 Avg Otbd Q (in-lbs)	2&3 Avg Inbd Q (in-lbs)
15	942.0	2.02	1.95	1.07	1.16
20	1258.0	3.35	3.42	1.99	2.05
25	1535.0	4.97	4.97	3.12	3.16
30	1755.0	6.45	6.42	4.14	4.16
36	2074.8	9.03	9.16	5.91	5.87
39	2358.8	11.87	11.98	7.63	7.69
42	2679.3	16.03	15.72	9.95	9.94

Table B10. MxWJ model-scale rotor forces at ship propulsion point - continued

JHSS MxWJ Rotor Forces at Previously Tested Fd Values										
Ship			1	2	3	4	1	2	3	4
Speed	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
(knots)	RPM	(lbs)	T (lbs)	T (lbs)	T (lbs)	T (lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)	Q (in-lbs)
15	930.5	2.44	1.88	1.88	1.91	2.06	0.98	1.06	1.21	1.10
20	1243.0	4.06	3.14	3.26	3.47	3.38	1.93	1.97	2.12	2.01
25	1518.5	6.05	4.65	4.84	4.87	4.97	3.09	3.10	3.11	3.05
30	1734.0	8.41	6.05	6.20	6.32	6.42	4.07	4.01	4.12	4.04
36	2051.0	11.62	8.63	8.57	9.31	8.91	5.81	5.62	5.83	5.77
39	2333.5	13.44	11.59	11.16	12.23	11.56	7.42	7.33	7.70	7.54
42	2656.8	15.35	15.15	14.63	16.21	16.21	9.98	9.55	9.94	9.58

Delta (Δ) Differences in Rotor Forces Ship Propulsion Point vs. Previously Tested Values										
Ship			1	2	3	4	1	2	3	4
Speed	Rotor	FD	Port Out	Port In	Stbd In	Stbd Out	Port Out	Port In	Stbd In	Stbd Out
(knots)	Δ RPM	Δ FD	Δ T	Δ T	Δ T	Δ T	Δ Q	Δ Q	Δ Q	Δ Q
15	1.2%	-5.7%	3.4%	2.9%	3.3%	1.9%	1.3%	2.8%	2.6%	3.0%
20	1.2%	-5.7%	2.6%	2.8%	0.8%	2.5%	2.3%	1.8%	-1.0%	0.3%
25	1.1%	-5.7%	4.0%	2.5%	2.2%	2.4%	1.3%	1.9%	1.8%	1.6%
30	1.2%	-5.7%	4.4%	2.8%	2.3%	2.7%	2.0%	2.5%	2.4%	2.3%
36	1.2%	-5.7%	3.1%	2.7%	2.4%	2.6%	1.8%	2.5%	2.4%	2.3%
39	1.1%	-5.7%	2.8%	2.5%	2.3%	2.5%	1.8%	2.3%	2.3%	2.2%
42	0.8%	-5.7%	2.6%	2.0%	1.9%	1.9%	1.6%	1.8%	2.1%	2.1%

Table B11. MxWJ dynamic sinkage and pitch, bare hull, three displacements

Mixed-Flow Waterjet, Bare Hull Resistance									
	Exp26 Bare Hull HVY			Exp27 Bare Hull DES			Exp28 Bare Hull LITE		
VS (knots)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)
15	0.45	0.18	-0.02	0.43	0.14	-0.02	0.47	0.14	-0.02
16	0.50	0.25	-0.01	0.49	0.17	-0.02	0.52	0.17	-0.02
17	0.59	0.27	-0.02	0.59	0.18	-0.03	0.60	0.17	-0.03
18	0.70	0.26	-0.03	0.70	0.17	-0.03	0.69	0.16	-0.03
19	0.80	0.25	-0.03	0.80	0.17	-0.04	0.77	0.17	-0.04
20	0.89	0.25	-0.04	0.89	0.19	-0.04	0.85	0.18	-0.04
21	0.97	0.28	-0.04	0.97	0.23	-0.04	0.92	0.21	-0.04
22	1.04	0.32	-0.04	1.04	0.27	-0.05	0.99	0.25	-0.05
23	1.11	0.37	-0.04	1.10	0.33	-0.05	1.07	0.28	-0.05
24	1.18	0.43	-0.05	1.17	0.38	-0.05	1.15	0.31	-0.05
25	1.26	0.49	-0.05	1.25	0.42	-0.05	1.26	0.33	-0.06
26	1.37	0.54	-0.05	1.35	0.45	-0.05	1.39	0.34	-0.06
27	1.49	0.57	-0.06	1.49	0.45	-0.06	1.54	0.32	-0.07
28	1.65	0.58	-0.06	1.65	0.44	-0.07	1.72	0.28	-0.09
29	1.84	0.58	-0.08	1.84	0.41	-0.09	1.93	0.22	-0.10
30	2.05	0.56	-0.09	2.07	0.36	-0.10	2.17	0.15	-0.12
31	2.29	0.53	-0.11	2.31	0.31	-0.12	2.42	0.08	-0.14
32	2.53	0.50	-0.12	2.57	0.26	-0.14	2.68	0.01	-0.16
33	2.78	0.49	-0.14	2.83	0.23	-0.16	2.94	-0.04	-0.18
34	3.01	0.51	-0.15	3.08	0.22	-0.17	3.19	-0.06	-0.20
35	3.21	0.58	-0.16	3.29	0.27	-0.18	3.40	-0.03	-0.21
36	3.36	0.71	-0.16	3.46	0.38	-0.19	3.57	0.06	-0.21
37	3.44	0.92	-0.15	3.56	0.57	-0.18	3.68	0.23	-0.21
38	3.44	1.22	-0.13	3.57	0.85	-0.16	3.72	0.48	-0.20
39	3.34	1.63	-0.10	3.50	1.23	-0.14	3.67	0.83	-0.17
40	3.14	2.14	-0.06	3.33	1.71	-0.10	3.53	1.28	-0.14
41	2.83	2.75	-0.01	3.05	2.28	-0.05	3.30	1.81	-0.09
42	2.42	3.44	0.06	2.68	2.92	0.01	2.98	2.41	-0.03
43	1.94	4.17	0.13	2.25	3.61	0.08	2.59	3.06	0.03
44	1.40	4.91	0.21	1.77	4.29	0.15	2.15	3.70	0.09
45	0.87	5.58	0.28	1.30	4.90	0.22	1.70	4.27	0.16

Table B12. MxWJ dynamic sinkage and pitch, powered vs. unpowered, design displacement

Mixed-Flow Waterjet, DES displacement						
	Exp27 Bare Hull DES			Exp32 Powered DES		
VS (knots)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)	Sinkage FP (ft)	Sinkage AP (ft)	Pitch Angle (degrees)
15	0.43	0.14	-0.02	0.25	0.33	0.01
16	0.49	0.17	-0.02	0.38	0.35	0.00
17	0.59	0.18	-0.03	0.46	0.40	0.00
18	0.70	0.17	-0.03	0.52	0.47	0.00
19	0.80	0.17	-0.04	0.56	0.54	0.00
20	0.89	0.19	-0.04	0.59	0.63	0.00
21	0.97	0.23	-0.04	0.62	0.70	0.01
22	1.04	0.27	-0.05	0.66	0.77	0.01
23	1.10	0.33	-0.05	0.71	0.83	0.01
24	1.17	0.38	-0.05	0.79	0.88	0.01
25	1.25	0.42	-0.05	0.89	0.91	0.00
26	1.35	0.45	-0.05	1.01	0.92	-0.01
27	1.49	0.45	-0.06	1.16	0.92	-0.01
28	1.65	0.44	-0.07	1.33	0.90	-0.03
29	1.84	0.41	-0.09	1.52	0.88	-0.04
30	2.07	0.36	-0.10	1.73	0.85	-0.05
31	2.31	0.31	-0.12	1.95	0.82	-0.07
32	2.57	0.26	-0.14	2.18	0.80	-0.08
33	2.83	0.23	-0.16	2.40	0.80	-0.10
34	3.08	0.22	-0.17	2.61	0.83	-0.11
35	3.29	0.27	-0.18	2.80	0.90	-0.11
36	3.46	0.38	-0.19	2.95	1.01	-0.12
37	3.56	0.57	-0.18	3.05	1.19	-0.11
38	3.57	0.85	-0.16	3.08	1.44	-0.10
39	3.50	1.23	-0.14	3.03	1.79	-0.07
40	3.33	1.71	-0.10	2.87	2.25	-0.04
41	3.05	2.28	-0.05	2.60	2.84	0.01
42	2.68	2.92	0.01	2.18	3.57	0.08
43	2.25	3.61	0.08			
44	1.77	4.29	0.15			
45	1.30	4.90	0.22			

APPENDIX C

Comparisons Between Waterjet Variants and JHSS Baseline Hull

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APPENDIX C FIGURES

TABLES OF APPENDIX A

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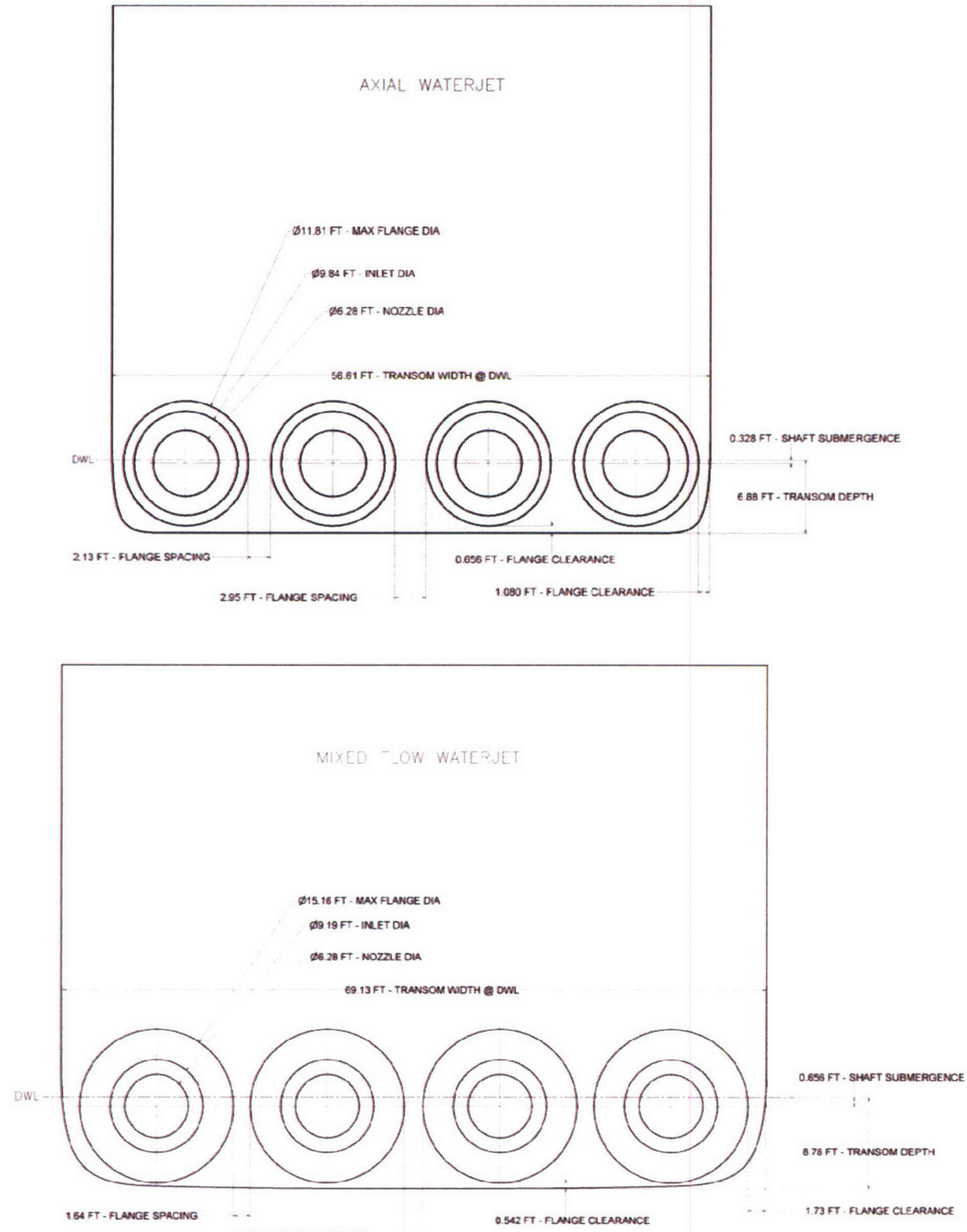


Fig C1. Target sketches of waterjet transoms, AxWJ and MxWJ

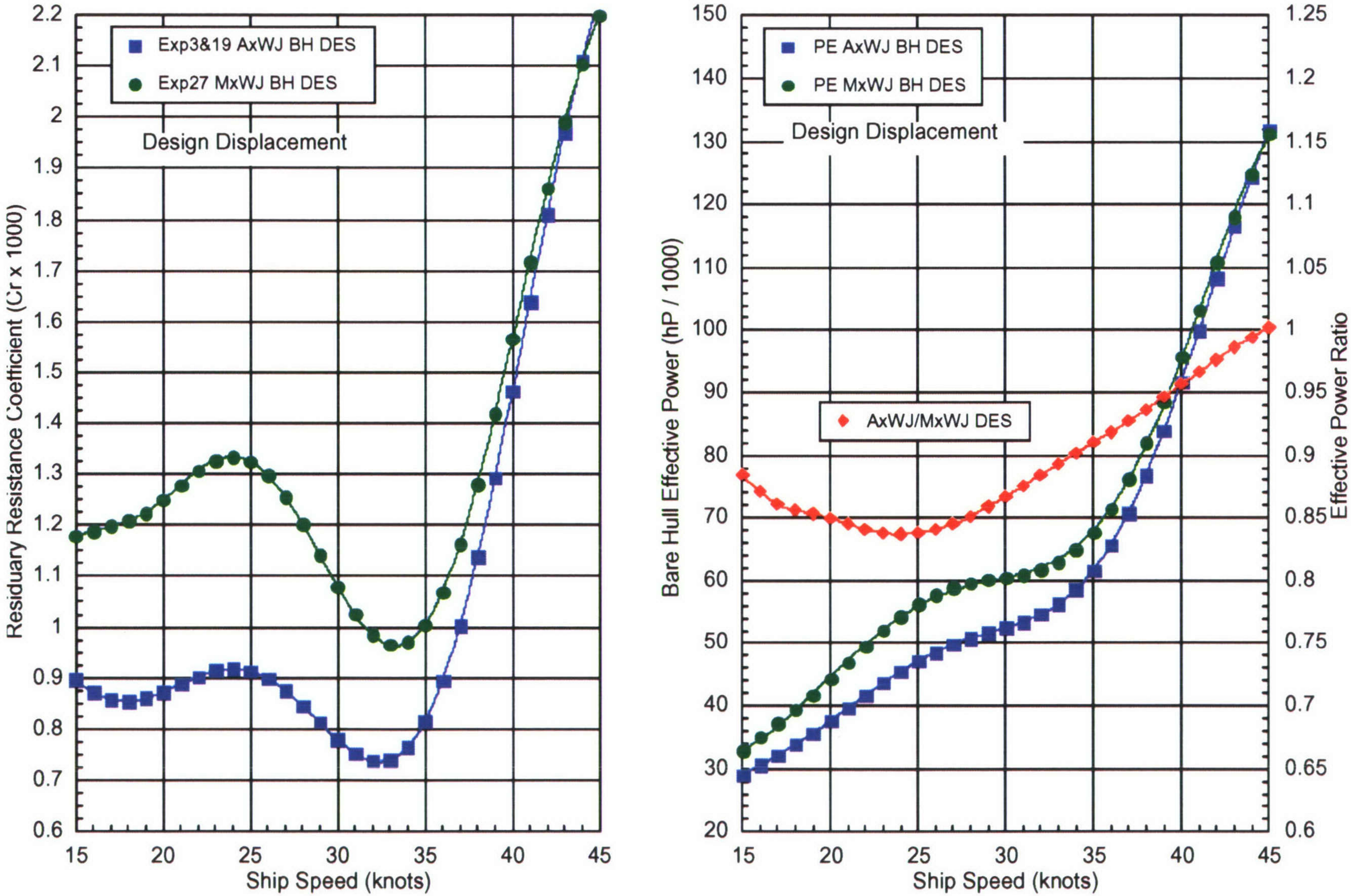
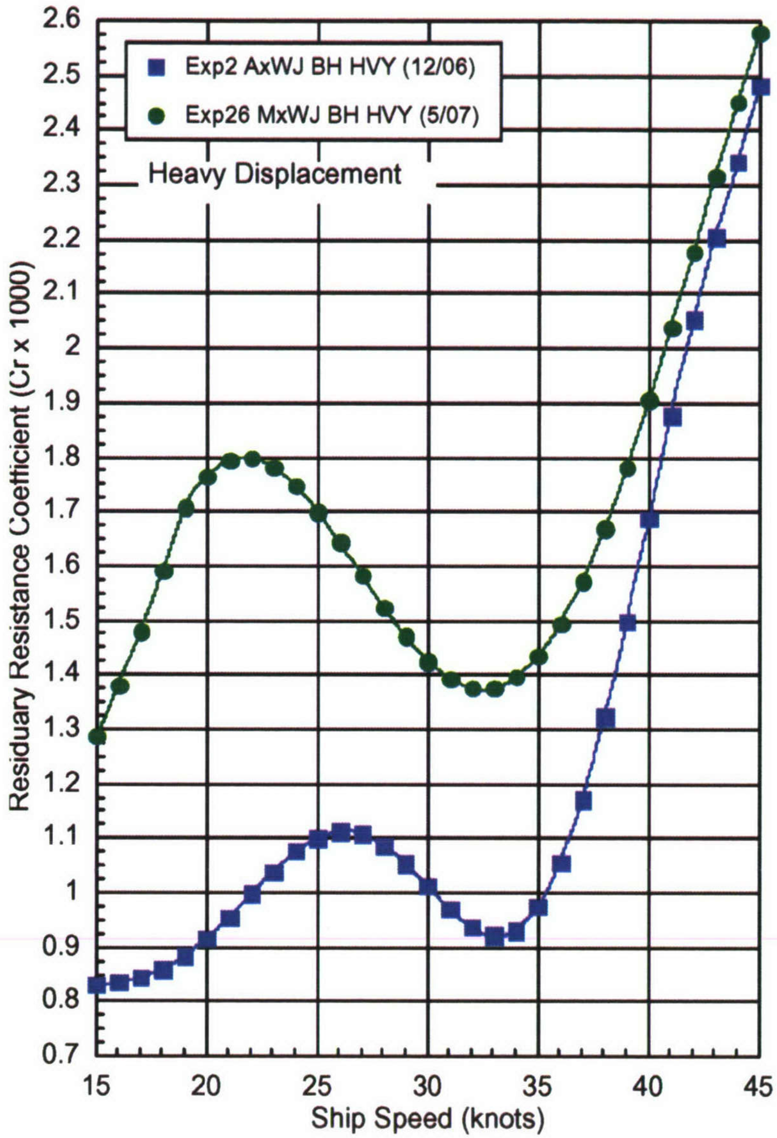


Fig C2. Bare hull resistance comparisons between MxWJ and AxWJ



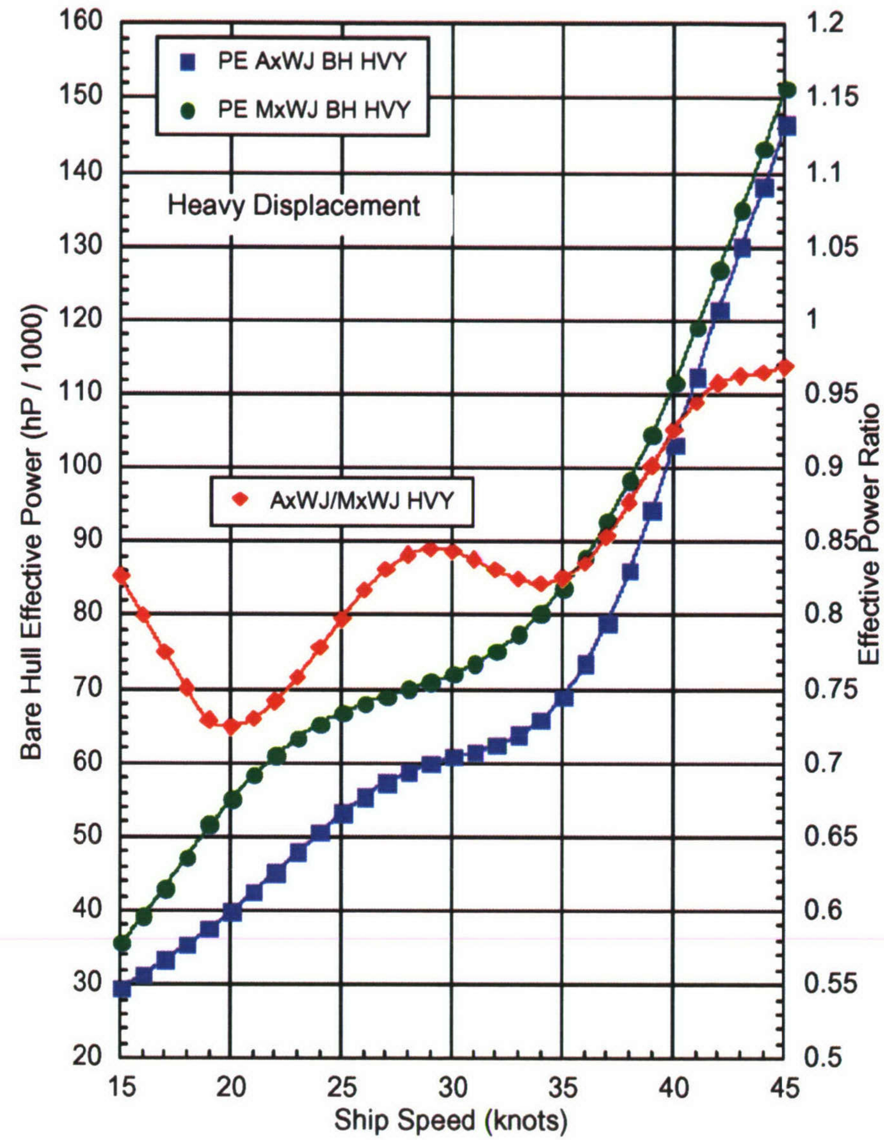


Fig C2. Bare hull resistance comparisons between MxWJ and AxWJ - continued

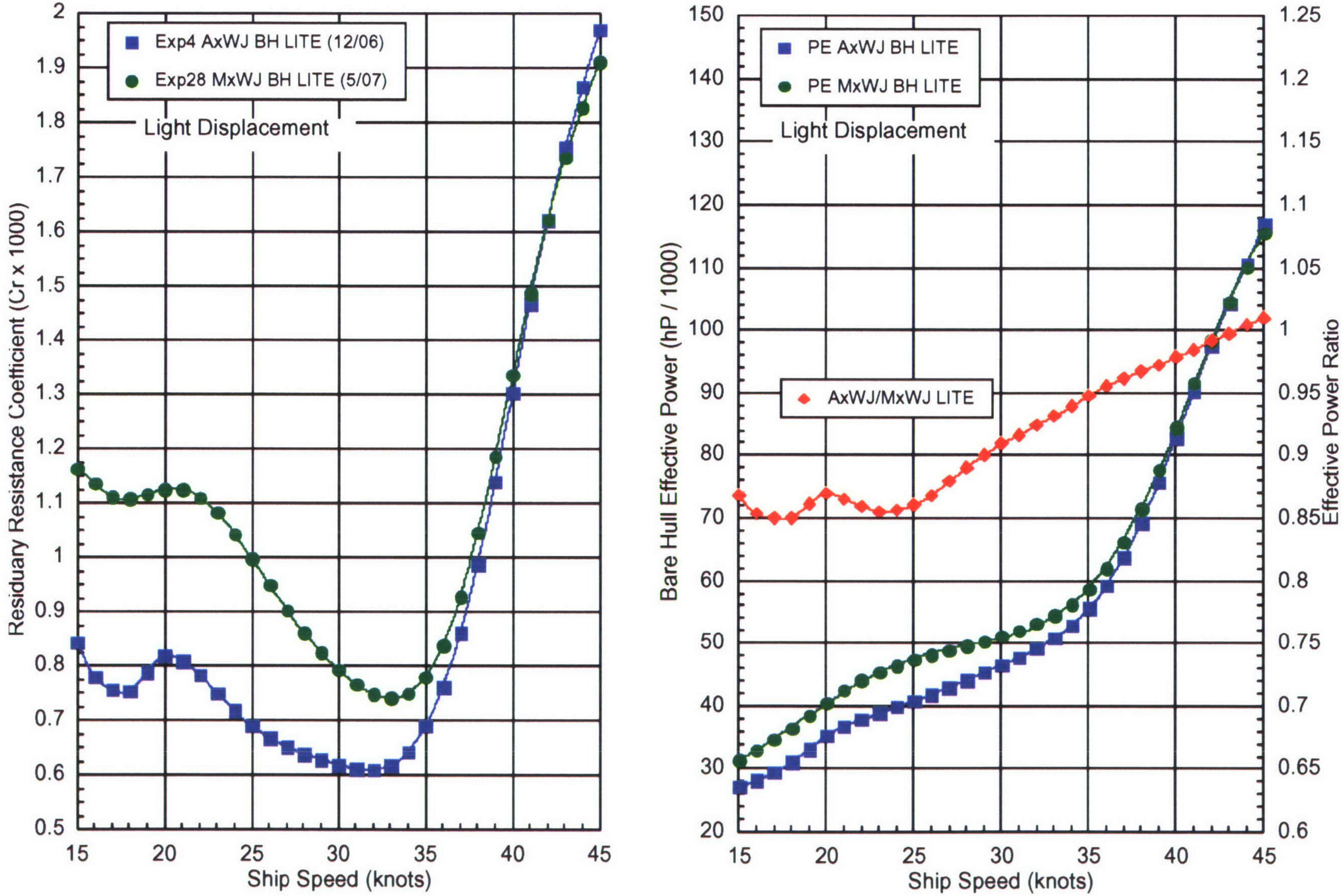


Fig C2. Bare hull resistance comparisons between MxWJ and AxWJ - continued

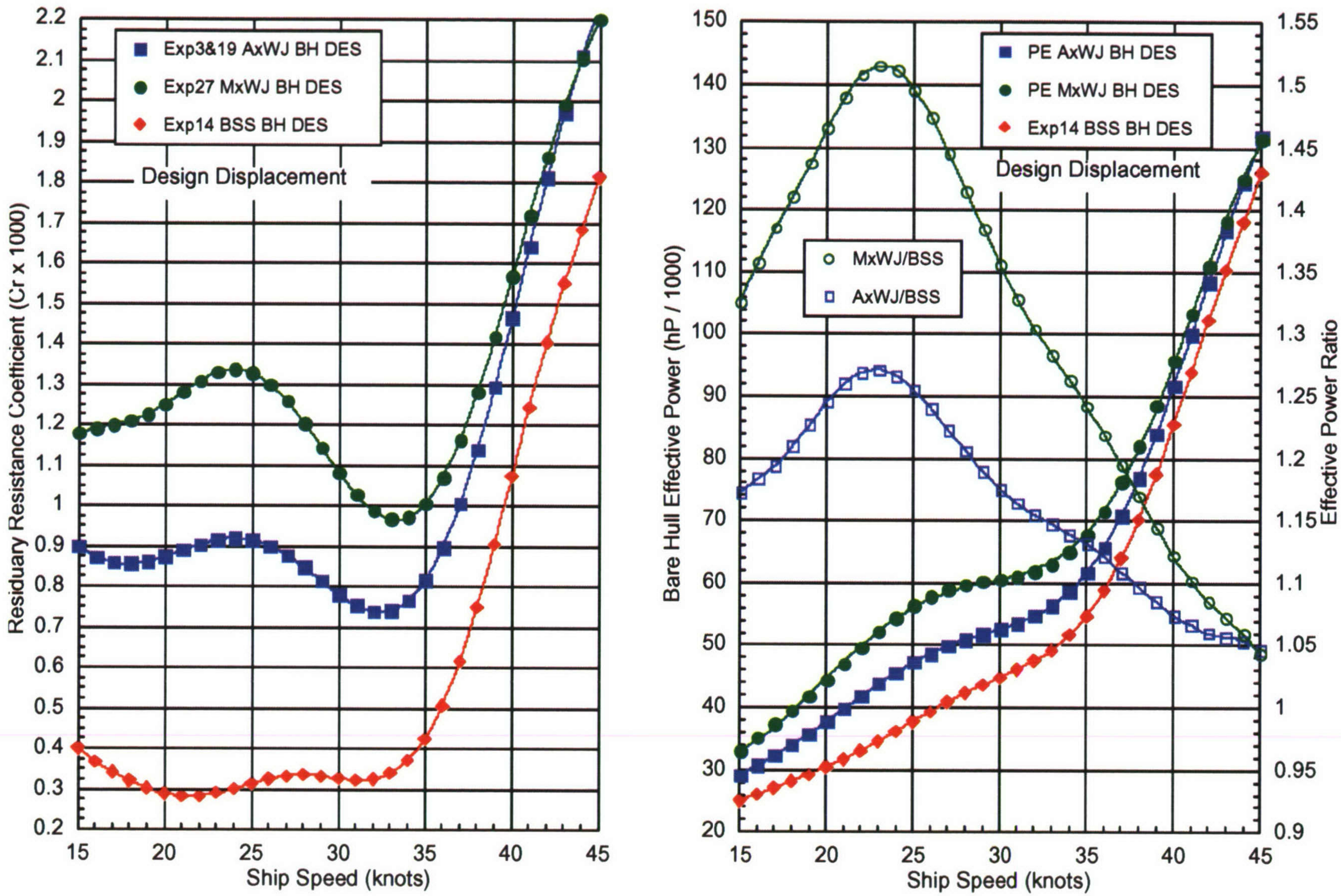
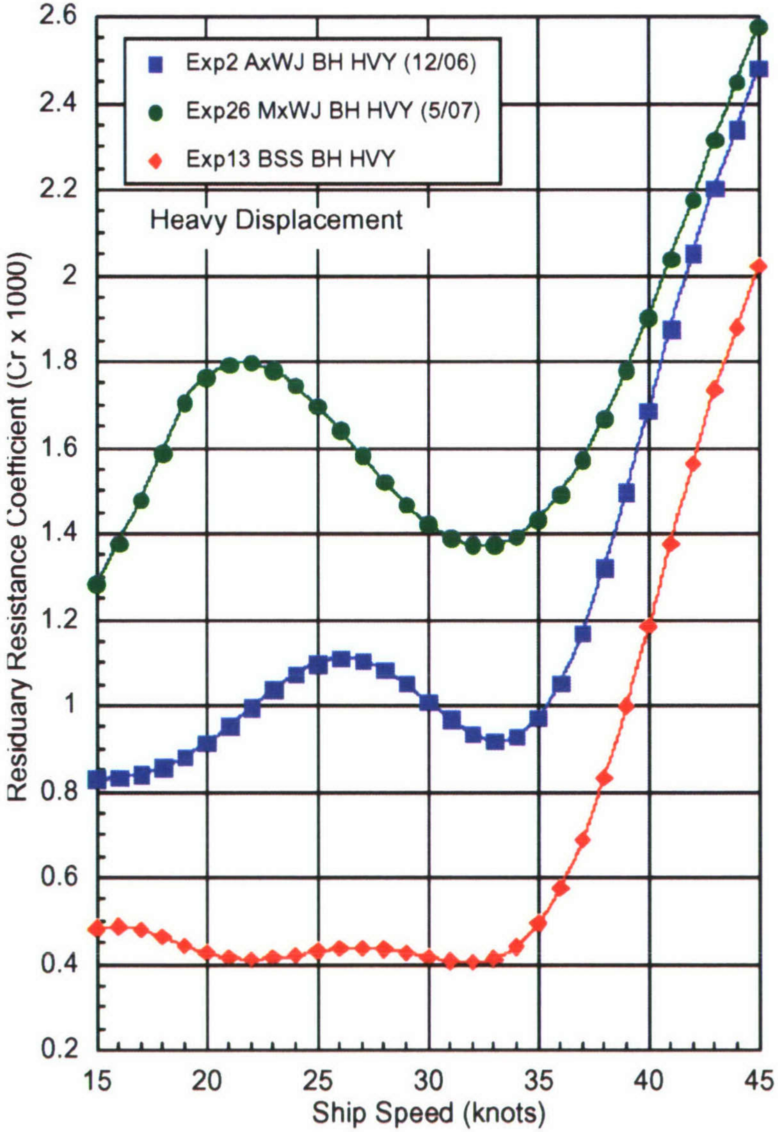


Fig C3. Bare hull resistance comparisons, waterjet variants MxWJ and AxWJ versus JHSS baseline BSS



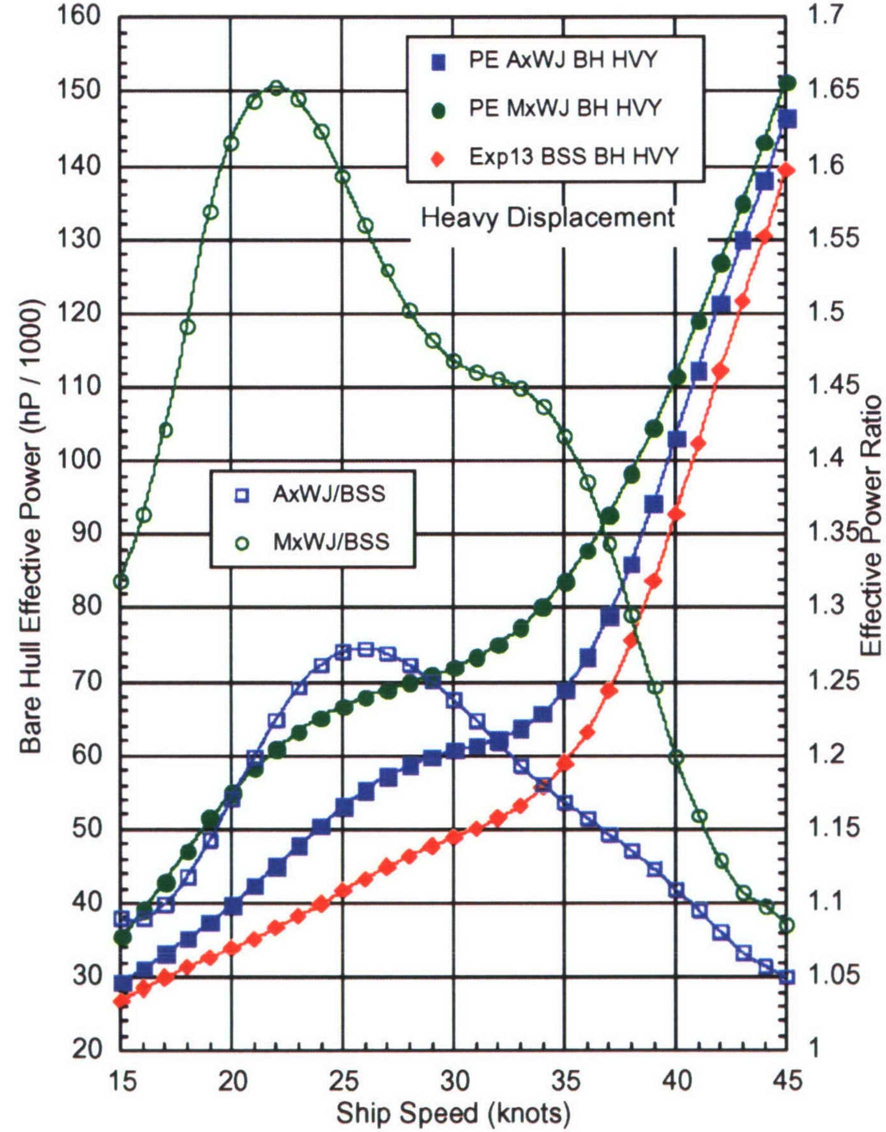
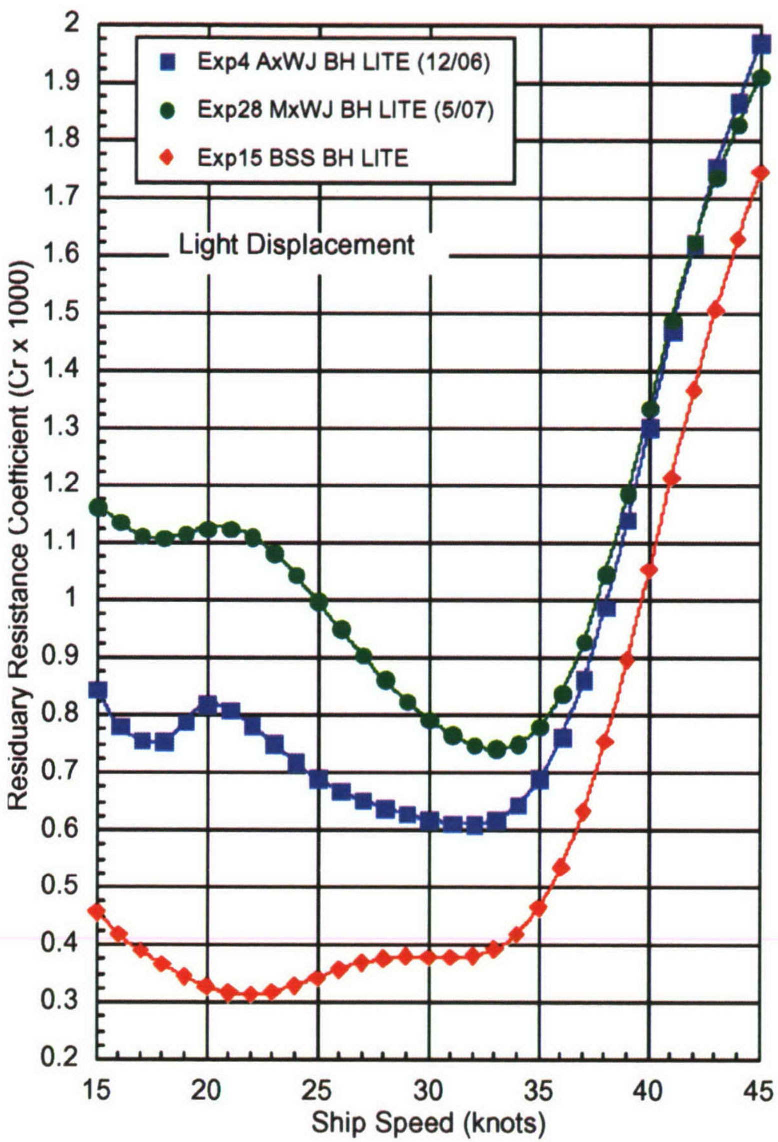


Fig C3. Bare hull resistance comparisons, waterjet variants MxWJ and AxWJ versus JHSS baseline BSS - continued



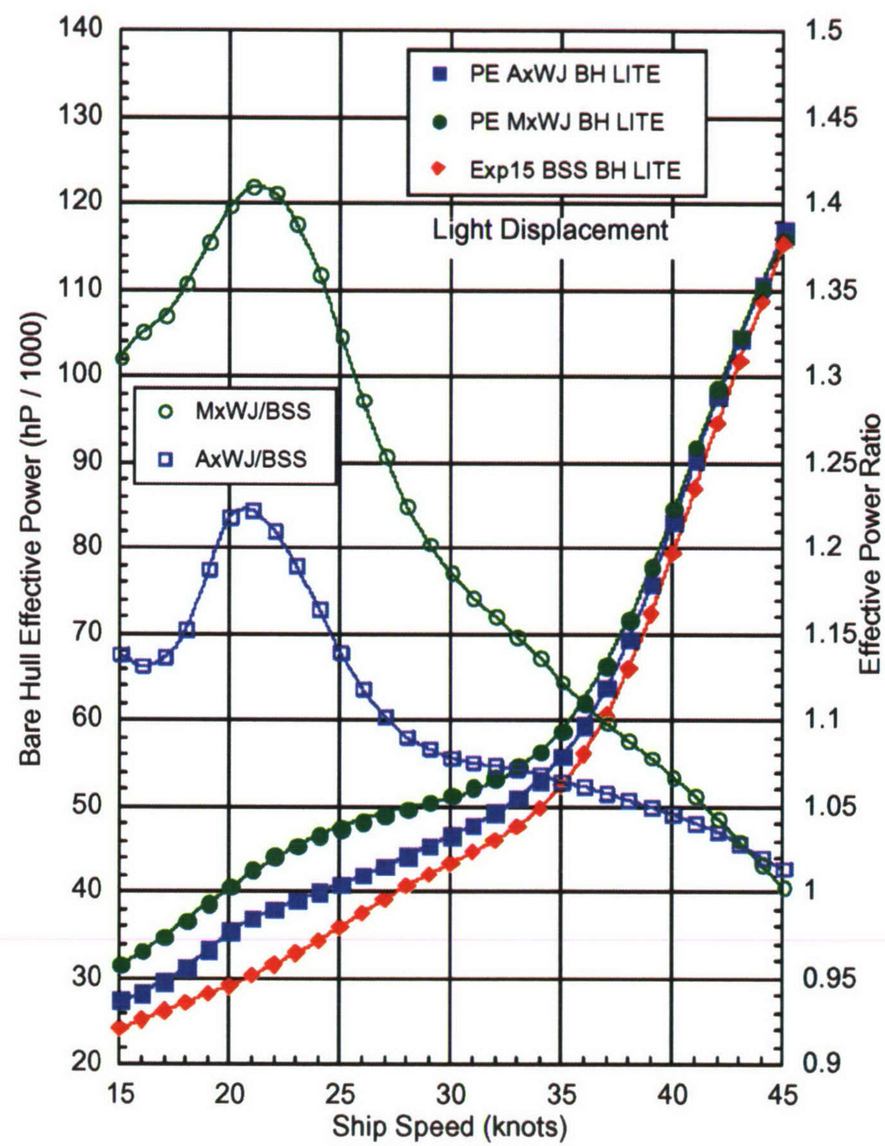


Fig C3. Bare hull resistance comparisons, waterjet variants MxWJ and AxWJ versus JHSS baseline BSS - continued

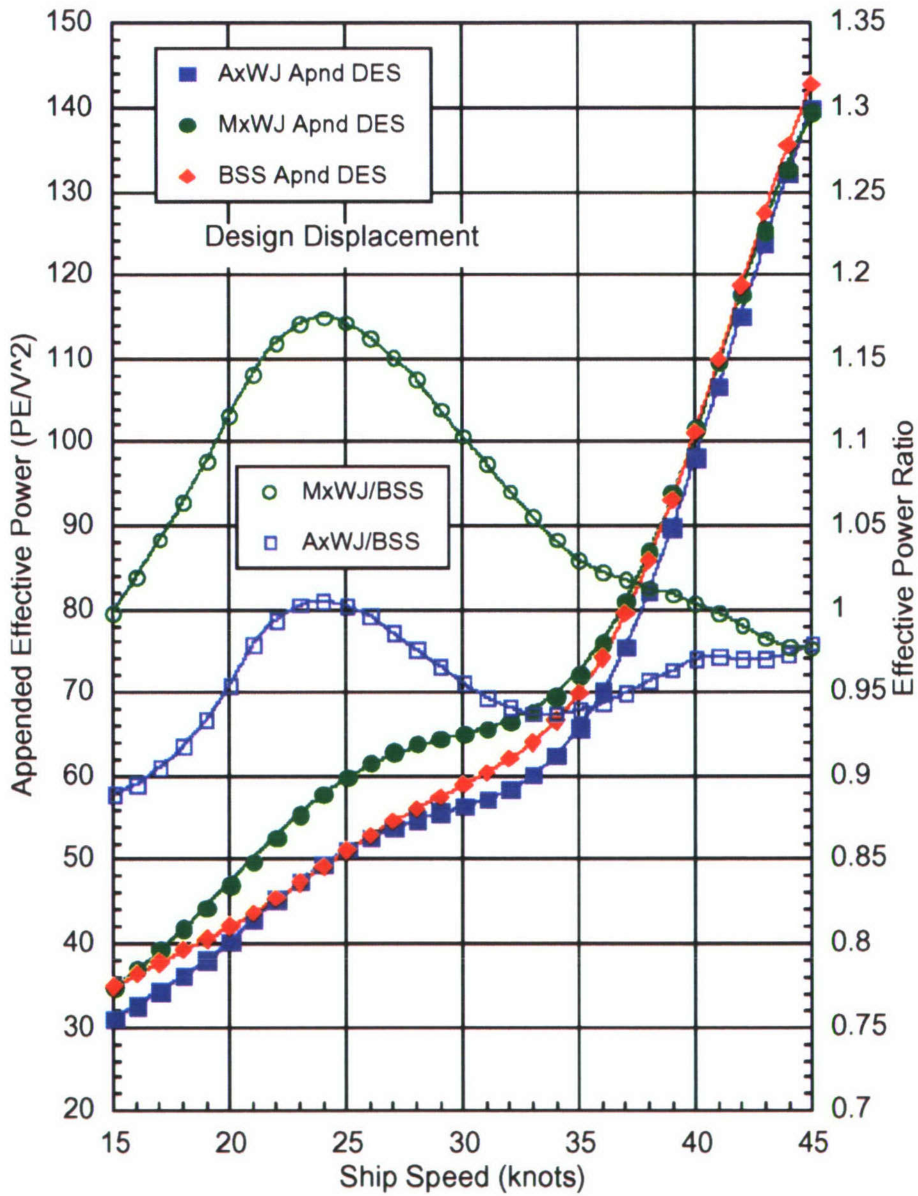


Fig C4. Appended resistance comparisons, AxWJ and MxWJ (with propulsion nozzles and estimated skeg drag) versus BSS (with skeg, shafts & struts, rudders, and stern flap)

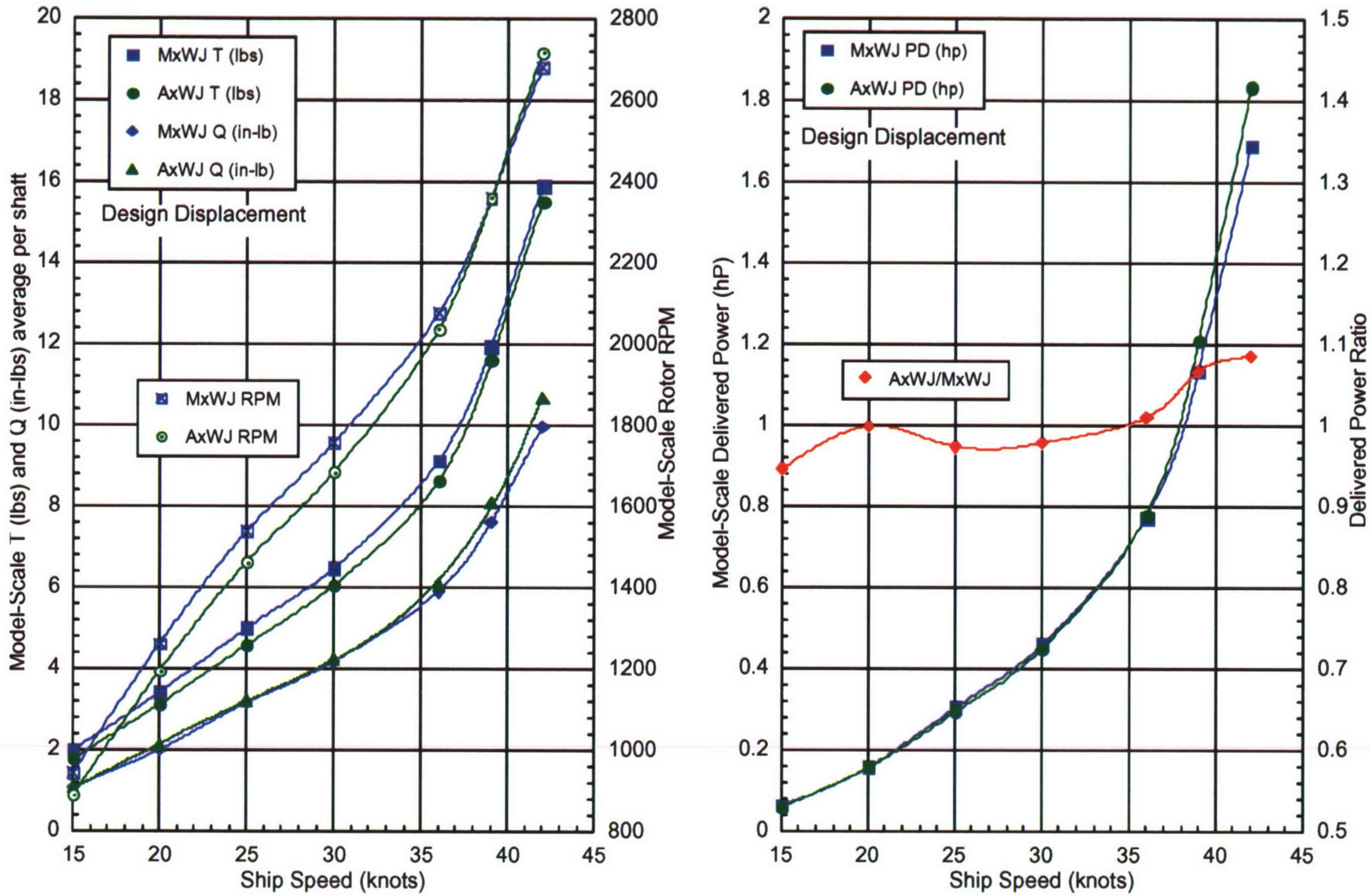


Fig C5. Model-scale rotor force comparisons between MxWJ and AxWJ

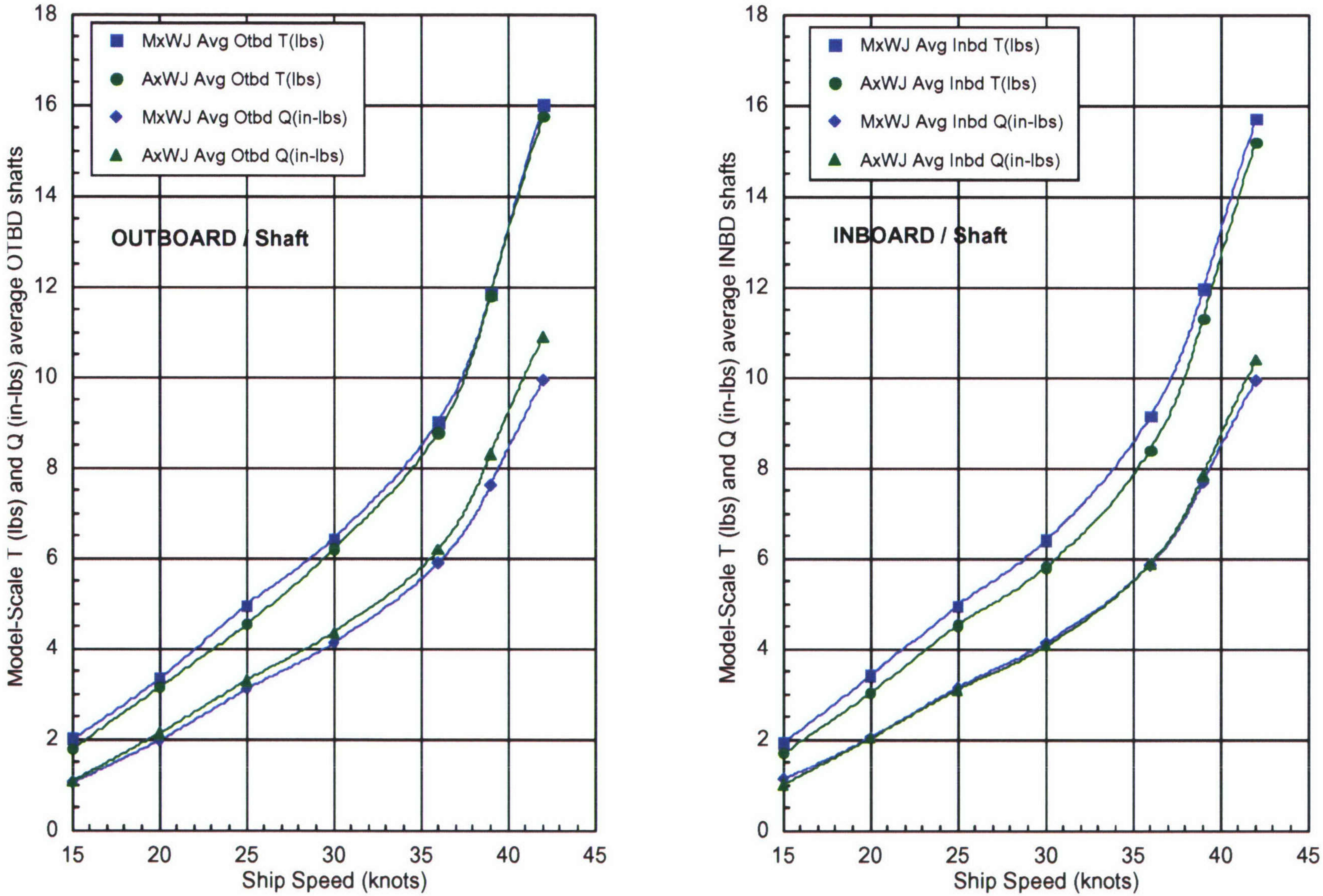


Fig C5. Model-scale rotor force comparisons between MxWJ and AxWJ - continued

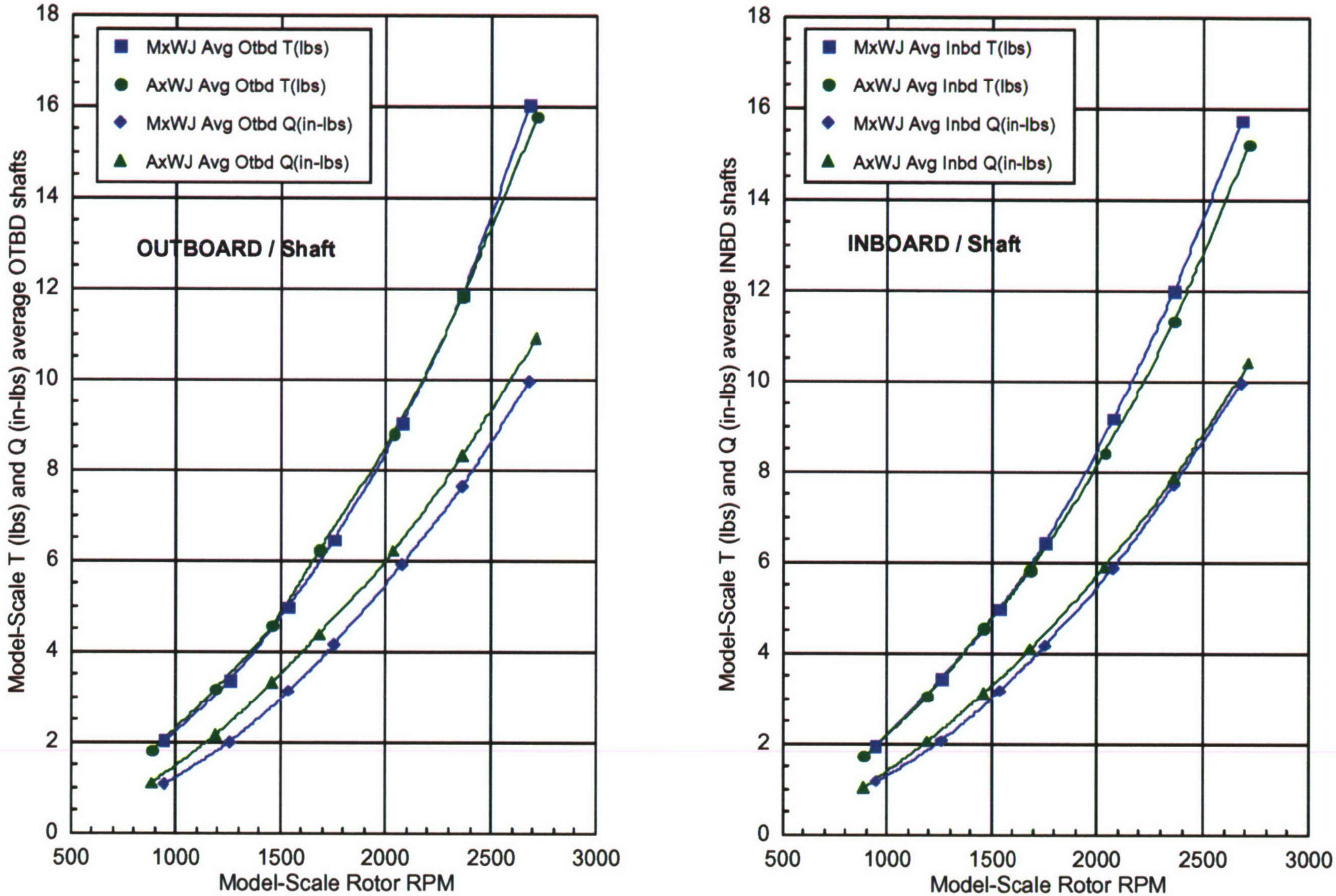


Fig C5. Model-scale rotor force comparisons between MxWJ and AxWJ - continued

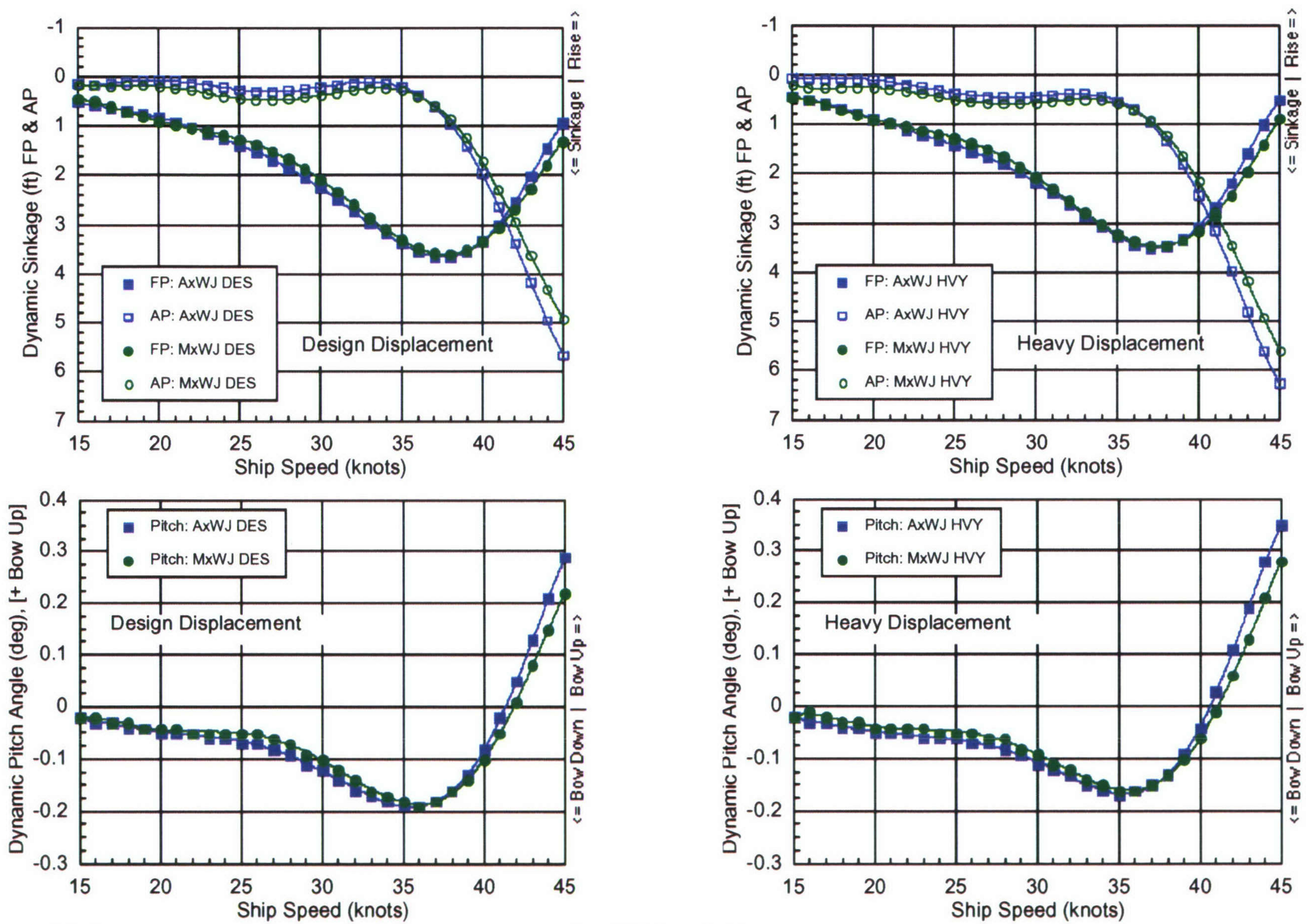


Fig C6. Sinkage and pitch comparisons between MxWJ and AxWJ, bare hull

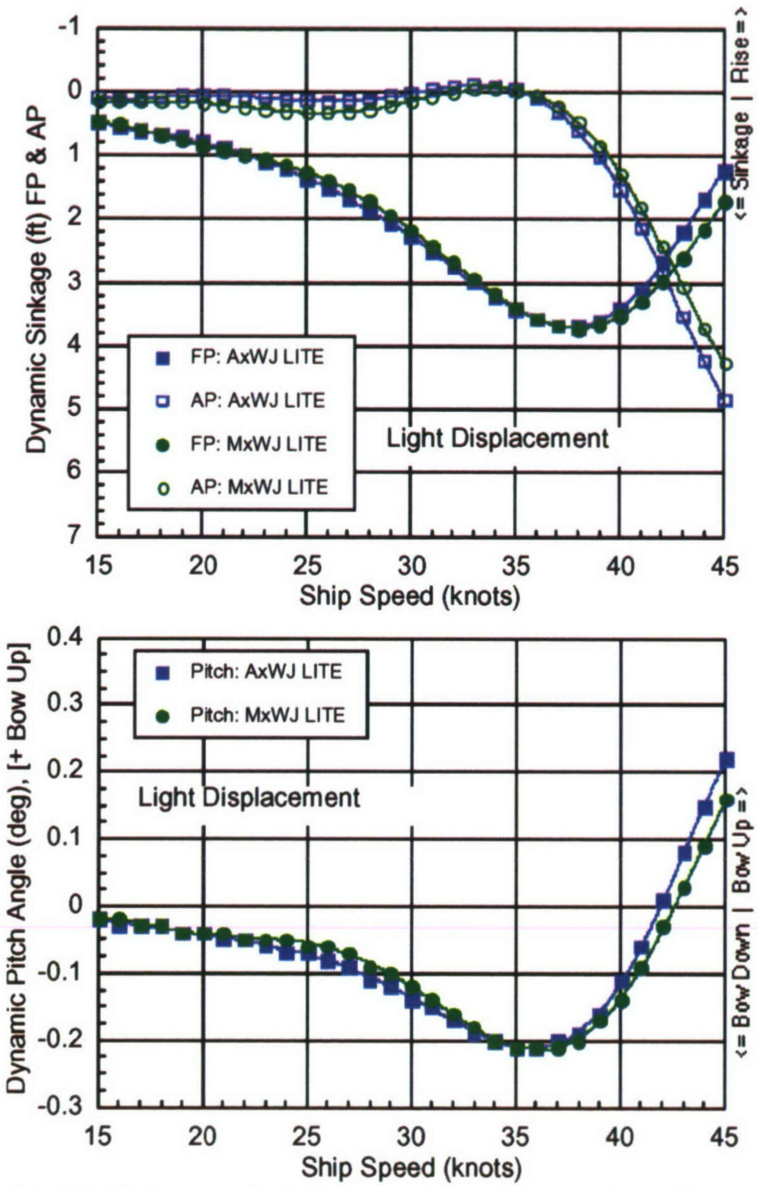


Fig C6. Sinkage and pitch comparisons between MxWJ and AxWJ, bare hull - continued

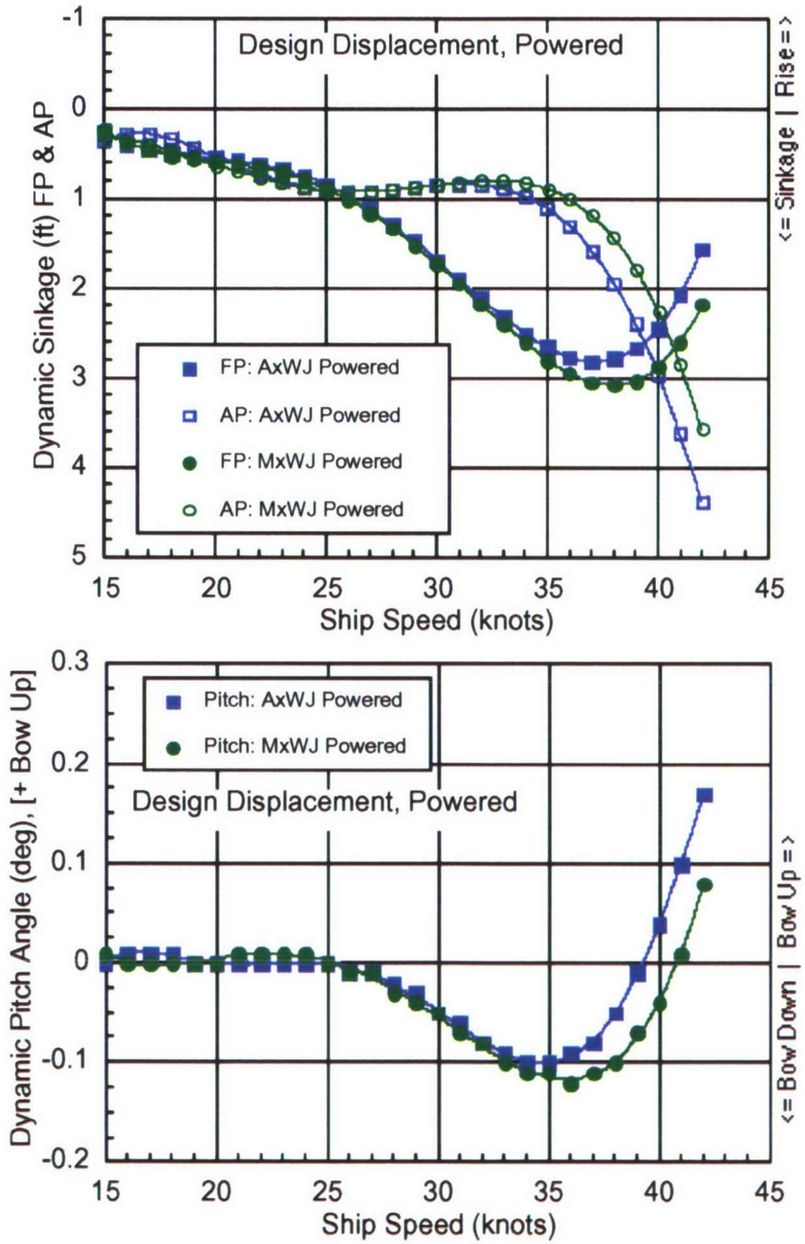


Fig C7. Sinkage and pitch comparisons between MxWJ and AxWJ, powered

Table C1. Transom design geometries, AxWJ and MxWJ

	Full-Scale Design Criteria			[4] Model-Scale Installation		
	AxWJ Design	MxWJ Design	AxWJ Δ%	AxWJ Model 5662	MxWJ Model 5662-1	AxWJ Δ%
Pump Inlet Diameter (ft)	9.84	9.19	+7%	10.02	10.02	0%
[1] Ratio: WJ Max Dia to Pump Inlet Dia	1.20	1.65	-27%	1.21	1.21	0%
[1] Waterjet Maximum Diameter (ft)	11.81	15.16	-22%	12.16	12.16	0%
Nozzle Exit Diameter (ft)	6.28	6.28	0%	6.26	6.28	0%
[2] Flange Clearance, Minimum Stipulated (ft)	1.64	1.64	0%	n/a	n/a	-
Flange Clearance, Inboard-to-Outboard Jets, port and starboard (ft)	2.13	1.64	+30%	n/a	n/a	-
Flange Clearance, Inboard Jets (ft)	2.95	1.84	+60%	n/a	n/a	-
[2] Pump Inlet Spacing, Inboard-to-Outboard Jet, port and starboard, center-to-center (ft)	13.94	16.80	-17%	13.94	16.80	-17%
Pump Inlet Clearance, Inbd-to-Otbd (ft)	4.10	7.61	-46%	4.10	7.61	-46%
Pump Inlet Clearance, Inbd-to-Otbd, Percent Pump Inlet Dia (%)	42%	83%	-50%	0.42	0.83	-50%
Pump Inlet Spacing, Inboard Jets (ft)	14.76	17.00	-13%	14.76	17.00	-13%
Pump Inlet Clearance, Inboard Jets (ft)	4.92	7.81	-37%	4.92	7.81	-37%
Pump Inlet Clearance, Inbd, Percent Pump Inlet Dia (%)	50%	85%	-41%	0.50	0.85	-41%
Minimum Transom Width, WJ MAX diam plus stipulated clearances (ft)	53.80	67.19	-20%	n/a	n/a	-
Transom Width (ft)	56.61	69.13	-18%	56.61	69.13	-18%
[3] Waterjet Submergence, Minimum Stipulated, Percent Pump Inlet Diameter (%)	50%	50%	-	n/a	n/a	-
Waterjet Submergence, Minimum Stipulated (ft)	4.92	4.59	+7%	n/a	n/a	-
Shaft Centerline Submergence, below DWL (ft)	0.33	0.66	-50%	0.33	0.66	-50%
Waterjet Submergence (ft)	5.25	5.25	0%	5.34	5.67	-6%
Percent Inlet Diameter Submerged (%)	53.3%	57.1%	-	53.3%	56.5%	-
[3] Transom Depth (ft)	6.88	8.78	-22%	6.88	8.78	-22%
*Flange-to-Hull Clearance (ft)	0.66	0.54	+21%	n/a	n/a	-
Transom Wetted Surface Area (ft^2)	377.4	577.3	-35%	377.4	577.3	-35%
Transom Volume aft of Station 15 (ft^3)	179,100	208,064	-14%	179,100	208,064	-14%

Table dimensions are Full-Scale. Depth, width, area and volumes correspond to design displacement (DES) of 36,491 tons

JHSS waterjet design criteria:

[1] Waterjet Maximum Diameter: Defined as the outer diameter (OD) of the mounting flange. A pump inlet diameter to maximum diameter ratio of 1:1.65 for the MxWJ was based on COTS Kamewa waterjets. A ratio of 1:1.20 was assumed by the HWG for the AxWJ.

[2] Flange Clearance / Pump Inlet Spacing: In order to allow for flange clearance, mounting hardware, and adequate access to machinery, it was stipulated by the HWG that the arrangements would required a minimum spacing (flange-to-flange clearance) of approximately 0.5m (1.64ft).

[3] Waterjet Submergence / Transom depth: In order to assure rotor priming, it was prescribed by the HWG that, at minimum, half of the waterjet diameter at the inlet was to remain submerged when at design displacement.

[4] Model-scale surrogate waterjet pumps were of identical design. Rotor Diameter = 3.485 inches, tip clearance = 20/1000 inch.

*Note: Flange-to-hull clearance is less than half of the stipulated flange-to-flange clearance.

Table C2. Bare hull resistance comparisons between waterjet variants MxWJ and AxWJ, and JHSS baseline BSS

AxWJ Model 5662 Bare Hull				MxWJ Model 5662-1 Bare Hull				Baseline (BSS) Model 5653-3 Bare Hull			
	Exp3&19 DES	Exp2 HVY	Exp4 LITE		Exp27 DES	Exp26 HVY	Exp28 LITE		Exp14 DES	Exp13 HVY	Exp15 LITE
Vs (kts)	PE (hp)	PE (hp)	PE (hp)	Vs (kts)	PE (hP)	PE (hP)	PE (hP)	Vs (kts)	PE (hp)	PE (hp)	PE (hp)
14	5441	5428	5234	14	6028	6344	5815	14	4715	4928	4577
15	6558	6631	6153	15	7409	8024	7079	15	5594	6082	5405
16	7836	8021	7226	16	8989	10038	8465	16	6624	7358	6389
17	9300	9616	8525	17	10783	12431	10017	17	7788	8742	7505
18	10978	11445	10066	18	12805	15270	11829	18	9079	10235	8740
19	12893	13549	11988	19	15099	18620	13909	19	10509	11857	10100
20	15064	15969	14119	20	17725	22059	16227	20	12102	13641	11604
21	17497	18738	16217	21	20694	25711	18724	21	13889	15627	13285
22	20183	21873	18358	22	23980	29533	21342	22	15905	17853	15179
23	23102	25364	20588	23	27536	33487	24038	23	18174	20348	17318
24	26219	29174	22955	24	31289	37546	26796	24	20707	23120	19721
25	29492	33237	25511	25	35158	41695	29625	25	23494	26158	22389
26	32877	37468	28304	26	39064	45941	32556	26	26509	29430	25308
27	36343	41777	31348	27	42949	50313	35630	27	29716	32894	28446
28	39878	46093	34635	28	46791	54867	38886	28	33078	36510	31769
29	43508	50383	38164	29	50616	59689	42361	29	36581	40260	35252
30	47306	54686	41929	30	54517	64891	46085	30	40248	44167	38902
31	51403	59129	45968	31	58656	70621	50104	31	44166	48324	42774
32	55997	63948	50411	32	63263	77048	54501	32	48496	52904	46992
33	61348	69488	55409	33	68630	84368	59428	33	53490	58180	51757
34	67770	76191	61251	34	75094	92794	65131	34	59478	64515	57348
35	75615	84561	68238	35	83008	102549	71956	35	66855	72350	64111
36	85242	95107	76820	36	92709	113855	80323	36	76039	82164	72424
37	96979	108271	87333	37	104480	126927	90782	37	87418	94422	82652
38	111078	124339	100110	38	118502	141956	103452	38	101274	109496	95084
39	127665	143358	115258	39	134824	159095	118399	39	117717	127593	109860
40	146705	165075	132615	40	153327	178449	135409	40	136626	148673	126917
41	167972	188946	151836	41	173725	200054	154083	41	157629	172407	145954
42	191065	214247	172221	42	195586	223870	173672	42	180182	198201	166473
43	215477	240364	193106	43	218408	249759	193488	43	203766	225319	187931
44	240758	267356	214306	44	241892	277480	213332	44	228320	252801	210073
45	266793	296893	236794	45	265913	306677	234218	45	254968	282500	233534

Table C2. Bare hull resistance comparisons between waterjet variants MxWJ and AxWJ, and JHSS baseline BSS - continued

Bare Hull PE Comparison AxWJ / MxWJ				Bare Hull PE Comparison AxWJ / BSS				Bare Hull PE Comparison MxWJ / BSS			
	DES	HVY	LITE		DES	HVY	LITE		DES	HVY	LITE
Vs (kts)	PE ratio	PE ratio	PE ratio	Vs (kts)	PE ratio	PE ratio	PE ratio	Vs (kts)	PE ratio	PE ratio	PE ratio
14	0.903	0.856	0.900	14	1.154	1.101	1.144	14	1.278	1.287	1.270
15	0.885	0.826	0.869	15	1.172	1.090	1.138	15	1.325	1.319	1.310
16	0.872	0.799	0.854	16	1.183	1.090	1.131	16	1.357	1.364	1.325
17	0.862	0.774	0.851	17	1.194	1.100	1.136	17	1.385	1.422	1.335
18	0.857	0.750	0.851	18	1.209	1.118	1.152	18	1.410	1.492	1.353
19	0.854	0.728	0.862	19	1.227	1.143	1.187	19	1.437	1.570	1.377
20	0.850	0.724	0.870	20	1.245	1.171	1.217	20	1.465	1.617	1.398
21	0.846	0.729	0.866	21	1.260	1.199	1.221	21	1.490	1.645	1.409
22	0.842	0.741	0.860	22	1.269	1.225	1.209	22	1.508	1.654	1.406
23	0.839	0.757	0.856	23	1.271	1.247	1.189	23	1.515	1.646	1.388
24	0.838	0.777	0.857	24	1.266	1.262	1.164	24	1.511	1.624	1.359
25	0.839	0.797	0.861	25	1.255	1.271	1.139	25	1.496	1.594	1.323
26	0.842	0.816	0.869	26	1.240	1.273	1.118	26	1.474	1.561	1.286
27	0.846	0.830	0.880	27	1.223	1.270	1.102	27	1.445	1.530	1.253
28	0.852	0.840	0.891	28	1.206	1.262	1.090	28	1.415	1.503	1.224
29	0.860	0.844	0.901	29	1.189	1.251	1.083	29	1.384	1.483	1.202
30	0.868	0.843	0.910	30	1.175	1.238	1.078	30	1.355	1.469	1.185
31	0.876	0.837	0.917	31	1.164	1.224	1.075	31	1.328	1.461	1.171
32	0.885	0.830	0.925	32	1.155	1.209	1.073	32	1.304	1.456	1.160
33	0.894	0.824	0.932	33	1.147	1.194	1.071	33	1.283	1.450	1.148
34	0.902	0.821	0.940	34	1.139	1.181	1.068	34	1.263	1.438	1.136
35	0.911	0.825	0.948	35	1.131	1.169	1.064	35	1.242	1.417	1.122
36	0.919	0.835	0.956	36	1.121	1.158	1.061	36	1.219	1.386	1.109
37	0.928	0.853	0.962	37	1.109	1.147	1.057	37	1.195	1.344	1.098
38	0.937	0.876	0.968	38	1.097	1.136	1.053	38	1.170	1.296	1.088
39	0.947	0.901	0.973	39	1.085	1.124	1.049	39	1.145	1.247	1.078
40	0.957	0.925	0.979	40	1.074	1.110	1.045	40	1.122	1.200	1.067
41	0.967	0.944	0.985	41	1.066	1.096	1.040	41	1.102	1.160	1.056
42	0.977	0.957	0.992	42	1.060	1.081	1.035	42	1.085	1.130	1.043
43	0.987	0.962	0.998	43	1.057	1.067	1.028	43	1.072	1.108	1.030
44	0.995	0.964	1.005	44	1.054	1.058	1.020	44	1.059	1.098	1.016
45	1.003	0.968	1.011	45	1.046	1.051	1.014	45	1.043	1.086	1.003
avg:	0.895	0.836	0.916	avg:	1.164	1.166	1.102	avg:	1.309	1.408	1.210

Table C3. Resistance comparisons for AxWJ and MxWJ with propulsion nozzles installed versus bare hull

AxWJ Propulsion Nozzles PE				MxWJ Rpropulsion Nozzles PE			
	Exp3&19 BH DES	Exp20 w/Nozzles DES	Noz/BH		Exp27 BH DES	Exp29 w/Nozzles DES	
Vs (kts)	PE (hp)	PE (hP)	PE ratio	Vs (kts)	PE (hP)	PE (hP)	
14	5441	5441	1.0	14	6028	6028	1.0
15	6558	6558	1.0	15	7409	7409	1.0
16	7836	7836	1.0	16	8989	8989	1.0
17	9300	9300	1.0	17	10783	10793	1.001
18	10978	10978	1.0	18	12805	12836	1.002
19	12893	12893	1.0	19	15099	15157	1.004
20	15064	15100	1.002	20	17725	17820	1.005
21	17497	17714	1.012	21	20694	20833	1.007
22	20183	20534	1.017	22	23980	24178	1.008
23	23102	23565	1.020	23	27536	27772	1.009
24	26219	26760	1.021	24	31289	31587	1.010
25	29492	30072	1.020	25	35158	35493	1.010
26	32877	33461	1.018	26	39064	39474	1.010
27	36343	36898	1.015	27	42949	43478	1.012
28	39878	40385	1.013	28	46791	47505	1.015
29	43508	43957	1.010	29	50616	51472	1.017
30	47306	47697	1.008	30	54517	55589	1.020
31	51403	51743	1.007	31	58656	59884	1.021
32	55997	56292	1.005	32	63263	64542	1.020
33	61348	61606	1.004	33	68630	69819	1.017
34	67770	68000	1.003	34	75094	76050	1.013
35	75615	75836	1.003	35	83008	83550	1.007
36	85242	85489	1.003	36	92709	93068	1.004
37	96979	97315	1.003	37	104480	104682	1.002
38	111078	111591	1.005	38	118502	118483	1.0
39	127665	128438	1.006	39	134824	134832	1.0
40	146705	147719	1.007	40	153327	153332	1.0
41	167972	168905	1.006	41	173725	173717	1.0
42	191065	191198	1.001	42	195586	195588	1.0
43	215477	215477	1.0	43	218408	218399	1.0
44	240758	240758	1.0	44	241892	241892	1.0
45	266793	266793	1.0	45	265913	265913	1.0
		avg:	1.007			avg:	1.007

Table C4. Appended resistances, AxWJ and MxWJ (with propulsion nozzles and estimated skeg drag) and BSS (with skeg, shafts & struts, rudders, and stern flap)

Appended* PE, Three Hulls				Appended* PE Comparisons			
Vs (kts)	Exp40 BSS PE (hP)	AxWJ PE (hP)	MxWJ PE (hP)	Vs (kts)	AxWJ / BSS PE ratio	MxWJ / BSS PE ratio	AxWJ / MxWJ PE ratio
14	6569	5812	6398	14	0.885	0.974	0.908
15	7868	7003	7854	15	0.890	0.998	0.892
16	9334	8366	9520	16	0.896	1.020	0.879
17	10962	9928	11421	17	0.906	1.042	0.869
18	12759	11717	13575	18	0.918	1.064	0.863
19	14709	13759	16023	19	0.935	1.089	0.859
20	16868	16112	18831	20	0.955	1.116	0.856
21	19298	18898	22017	21	0.979	1.141	0.858
22	22025	21902	25546	22	0.994	1.160	0.857
23	25058	25130	29338	23	1.003	1.171	0.857
24	28387	28533	33361	24	1.005	1.175	0.855
25	31987	32060	37481	25	1.002	1.172	0.855
26	35824	35666	41680	26	0.996	1.163	0.856
27	39865	39324	45903	27	0.986	1.151	0.857
28	44090	43033	50153	28	0.976	1.138	0.858
29	48505	46832	54346	29	0.966	1.120	0.862
30	53157	50808	58699	30	0.956	1.104	0.866
31	58151	55108	63249	31	0.948	1.088	0.871
32	63654	59943	68193	32	0.942	1.071	0.879
33	69902	65590	73803	33	0.938	1.056	0.889
34	77197	72386	80436	34	0.938	1.042	0.900
35	85888	80714	88428	35	0.940	1.030	0.913
36	96351	90973	98552	36	0.944	1.023	0.923
37	108950	103540	110907	37	0.950	1.018	0.934
38	123990	118710	125602	38	0.957	1.013	0.945
39	141663	136609	143003	39	0.964	1.009	0.955
40	161993	157090	162703	40	0.970	1.004	0.966
41	184792	179590	184402	41	0.972	0.998	0.974
42	209631	203259	207649	42	0.970	0.991	0.979
43	235856	229032	231954	43	0.971	0.983	0.987
44	262665	255860	256994	44	0.974	0.978	0.996
45	289282	283481	282601	45	0.980	0.977	1.003
				avg:	0.956	1.065	0.901

*BSS with Skeg, Shafts&Struts, Rudders and Flap;
Waterjet Hulls with Propulsion Nozzles and Estimated Skeg Drag

Table C5. Model-scale rotor force comparisons between MxWJ and AxWJ, ship propulsion point

JHSS MxWJ Rotor Forces at Ship Propulsion Point										
VS (Knots)	Rotor RPM	INBD/Shaft T (lbs)	OTBD/Shaft T (lbs)	Total T (lbs)	INBD/Shaft Q (in-lbs)	OTBD/Shaft Q (in-lbs)	Total Q (in-lbs)	INBD/Shaft (hP)	OTBD/Shaft (hP)	Total SHP
15	942.0	1.95	2.02	7.95	1.04	1.07	4.22	0.016	0.016	0.06
20	1258.0	3.42	3.35	13.54	1.99	1.99	7.96	0.040	0.040	0.16
25	1535.0	4.97	4.97	19.87	3.14	3.12	12.52	0.077	0.076	0.30
30	1755.0	6.42	6.45	25.75	4.13	4.14	16.55	0.115	0.115	0.46
36	2074.8	9.16	9.03	36.38	5.84	5.91	23.49	0.192	0.194	0.77
39	2358.8	11.98	11.87	47.70	7.53	7.63	30.31	0.282	0.285	1.13
42	2679.3	15.72	16.03	63.50	9.93	9.95	39.77	0.422	0.423	1.69

JHSS AxWJ Rotor Forces at Ship Propulsion Point										
VS (Knots)	Rotor RPM	INBD/Shaft T (lbs)	OTBD/Shaft T (lbs)	Total T (lbs)	INBD/Shaft Q (in-lbs)	OTBD/Shaft Q (in-lbs)	Total Q (in-lbs)	INBD/Shaft (hP)	OTBD/Shaft (hP)	Total SHP
15	887.0	1.72	1.80	7.05	1.03	1.09	4.24	0.014	0.015	0.06
20	1191.5	3.04	3.16	12.41	2.04	2.15	8.39	0.039	0.041	0.16
25	1460.0	4.54	4.56	18.21	3.10	3.30	12.80	0.072	0.076	0.30
30	1681.8	5.83	6.22	24.11	4.08	4.37	16.89	0.109	0.116	0.45
36	2035.3	8.41	8.78	34.38	5.89	6.20	24.17	0.190	0.200	0.78
39	2358.8	11.33	11.83	46.32	7.85	8.31	32.33	0.294	0.311	1.21
42	2713.8	15.21	15.76	61.94	10.40	10.90	42.60	0.448	0.469	1.83

Delta (Δ) Differences in Rotor Forces at Ship Propulsion Point AxWJ vs. MxWJ										
VS (knots)	Rotor Δ RPM	INBD/Shaft Δ T	OTBD/Shaft Δ T	Total Δ T	INBD/Shaft Δ Q	OTBD/Shaft Δ Q	Total Δ Q	INBD/Shaft Δ hP	OTBD/Shaft Δ hP	Total Δ hP
15	-5.8%	-11.6%	-11.0%	-11.3%	-1.4%	2.3%	0.5%	-7.2%	-3.6%	-5.4%
20	-5.3%	-11.1%	-5.5%	-8.3%	2.6%	8.1%	5.4%	-2.8%	2.4%	-0.2%
25	-4.9%	-8.6%	-8.1%	-8.3%	-1.3%	5.9%	2.3%	-6.1%	0.7%	-2.7%
30	-4.2%	-9.1%	-3.6%	-6.3%	-1.2%	5.4%	2.1%	-5.4%	1.0%	-2.2%
36	-1.9%	-8.2%	-2.8%	-5.5%	0.9%	4.9%	2.9%	-1.0%	2.9%	0.9%
39	0.0%	-5.4%	-0.3%	-2.9%	4.3%	9.0%	6.7%	4.3%	9.0%	6.7%
42	1.3%	-3.3%	-1.6%	-2.5%	4.7%	9.5%	7.1%	6.1%	10.9%	8.5%

APPENDIX D

Hull Surface Survey Measurements

by
Ann Marie Powers

Overview

Model 5662 Design Specifications
Station Spacing: 16.71 in
LBP = 334.2 in
Scale = 34.122

Model 5662-1 Design Specifications
Station Spacing: 16.71 in
LBP = 334.2 in
Scale = 34.122

Laser Tracker and Measurement
The Faro Xi Laser Tracker is calibrated yearly by the manufacturer and is traceable to NIST standards. The current calibration is valid through October 18, 2007. A copy of this certificate is provided.

The Laser Tracker was used to measure Model 5662 for Code 5800 on Feb. 12 2007. The data for this model is located in Insight file: Feb12Model5662Waterjets.SMX, and is available from Code 653. The data was compared to its CAD file (JHSS_AXIAL_WJ_06_12_2006.igs).

Model 5662 was built without a bulb, and was later outfitted with the gooseneck bulb. In addition, it was built as a two piece model with a watertight joint at station 10. This appendix documents the measurements on the model with the gooseneck bulb insert. Model 5662 was built without bilge keels or a skeg. Later, PVC bilge keels were installed on the Model, but were not laser tracked.

Model 5662-1 is comprised of the forward half of Model 5662 and a different aft half that incorporated the mixed flow hull geometry and the waterjet assembly. It was measured with the Laser Tracker on Aug. 21, 2007, and compared to its CAD file (JHSS_MIXFL_WJ_06_10_2006.igs). The skeg was added for a later phase of testing, and was never measured. Model 5662-1 has bilge keels, which were measured, but are not documented in this appendix.

In order for the models to pass the construction criteria, 75% or more of the model surfaces must be within ± 2 mm (0.787 in) of the design CAD file. In this appendix, the percent of points (not surfaces) in tolerance are provided.

For both models, Code 5800 requested that the best fit to CAD file be done using only the surfaces below the waterline. The following appendix contains contour plots for both models in their best fit positions.

The details of the water-jets were not provided in the CAD files, so for the purposes of this analysis, the water-jet point cloud data was excluded.

Figure D1 illustrates the 120,000 data points which are spread over the hull of Model 5662 and the 470,000 data points which are spread over the hull of Model 5662-1. The points on the Model 5662 hull are spaced every 0.5 in, while the points on the Model 5662-1 hull are spaced every 0.1 in.

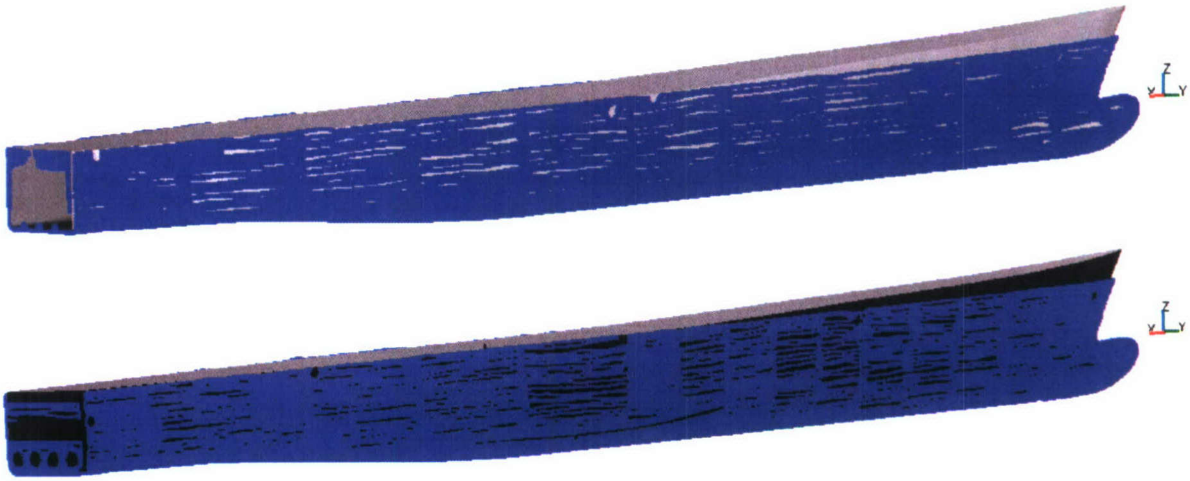


Figure D1. Model 5662 and Model 5662-1 point cloud data superimposed on their respective CAD surfaces.

Table D1 displays the summary statistics for the deviations from the measured point cloud data to the CAD surfaces. These maximum and average distances are measured along the normal vectors of the CAD surfaces. The absolute values of these distances are presented in Table D1.

Table D1. Data summary statistics.

		Absolute Value of Maximum (in)	Absolute Value of Average (in)	Standard Deviation (in)
	Entire Hull	0.090	0.030	0.016
Model 5662	Under Waterline	0.090	0.031	0.015
	Entire Hull	0.140	0.031	0.021
Model 5662-1	Under Waterline	0.140	0.033	0.022

Coordinate System

The origin is located at the point where the forward perpendicular (FP) meets the waterline (Figure D2). The positive X-axis extends toward the stern of the model, and the positive y-axis extends toward the starboard side of the model. Therefore, the positive z-axis points aloft.

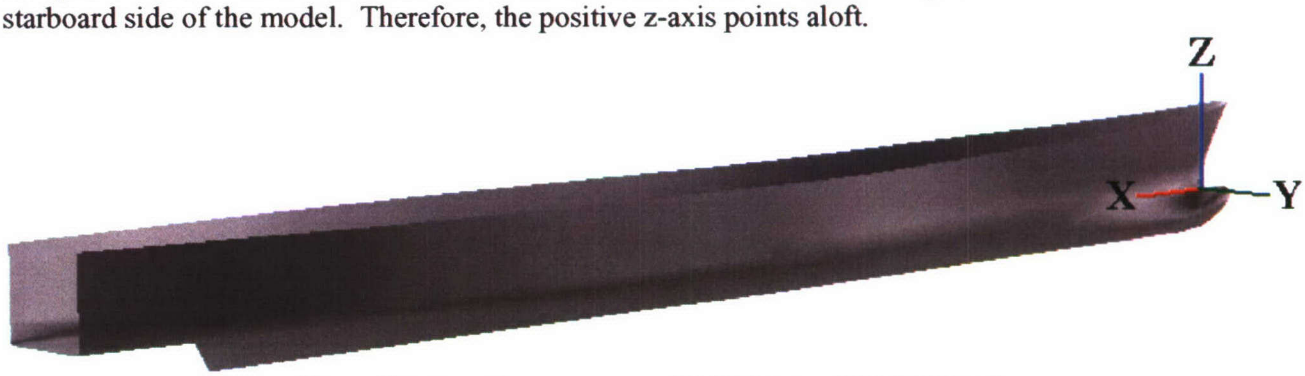


Figure D2. Coordinate system on Model 5662 and Model 5662-1.

Model 5662 Hull Surface Analysis

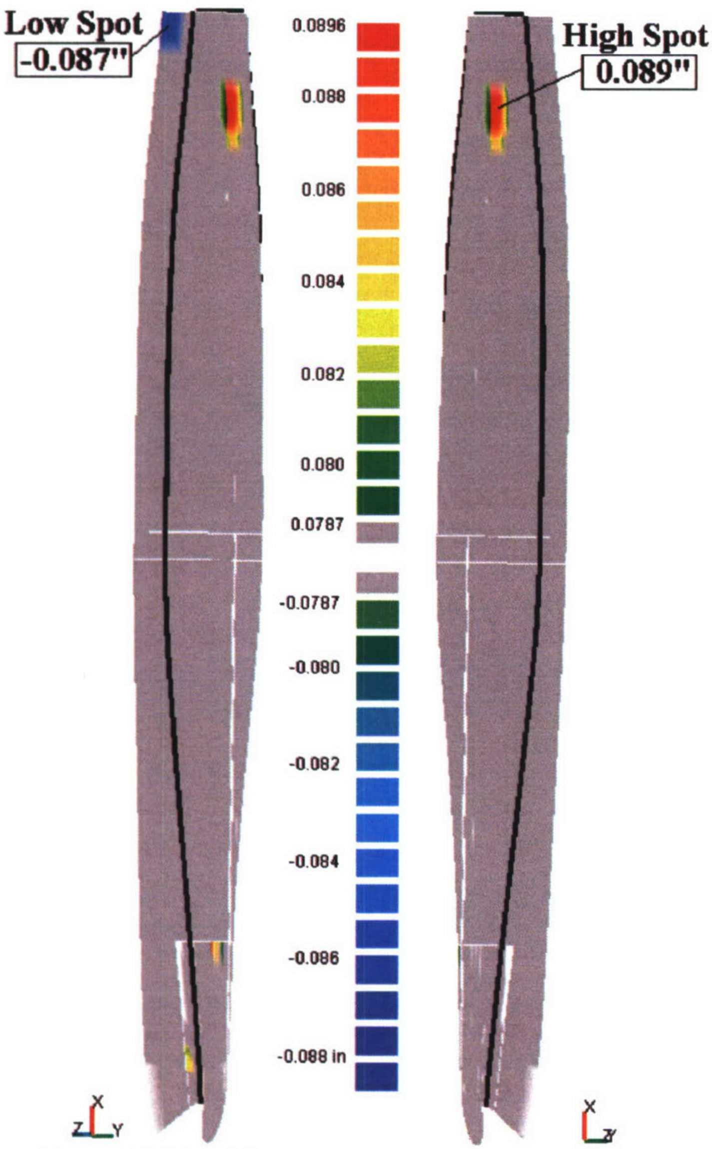


Figure D3. Model 5662: Oblique view of port and starboard regions out of 2mm tolerance. The black line represents the waterline.

Model 5662: Areas out of tolerance
99.6% of the measured points below the waterline fall within ± 2mm (0.0787 in) of the CAD file. 99.7% of all of the measured points (~120,000 points) on the model fall within ± 2mm (0.0787 in) of the CAD file.

The maximum positive deviation from the measured points to the CAD file is 0.089 in, while the maximum negative deviation is -0.087 in. The negative deviation (-0.087 in) in the port outboard aft region (shown as blue in Figure D3), is a low spot. The positive deviation (shown in red) is a high spot.

The gray regions are within the ± 2 mm (0.0787 in) tolerance.

Model 5662: Transom

Figure D4 illustrates the fit on the transom. The blue edge represents a low spot (-0.084 in from the CAD surface). Note that much of the transom surface was not measured. Very little of the transom area was accessible because of the water-jet structures.

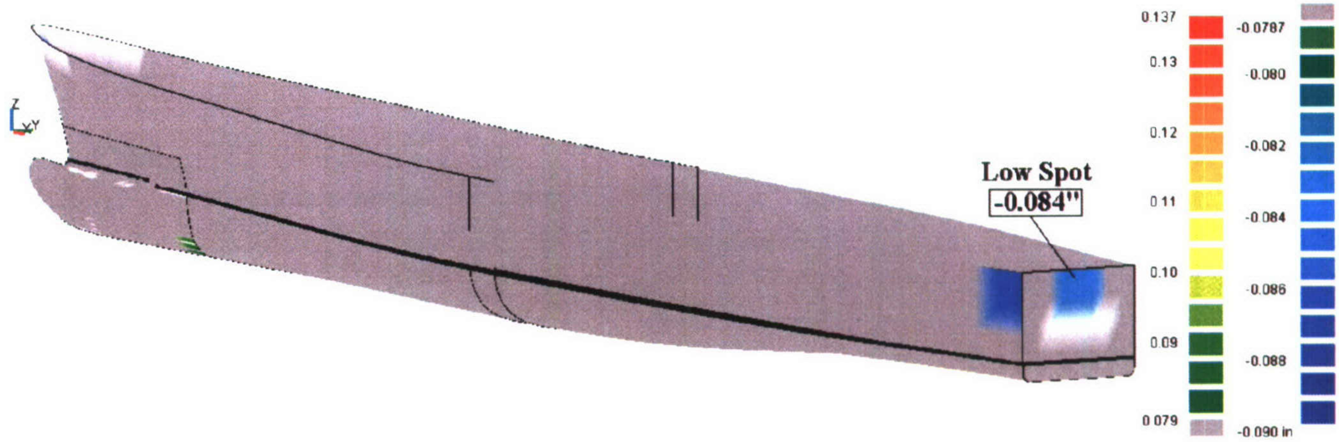


Figure D4. Transom view of Model 5662. The black line represents the waterline.

Model 5662-1 Hull Surface Analysis

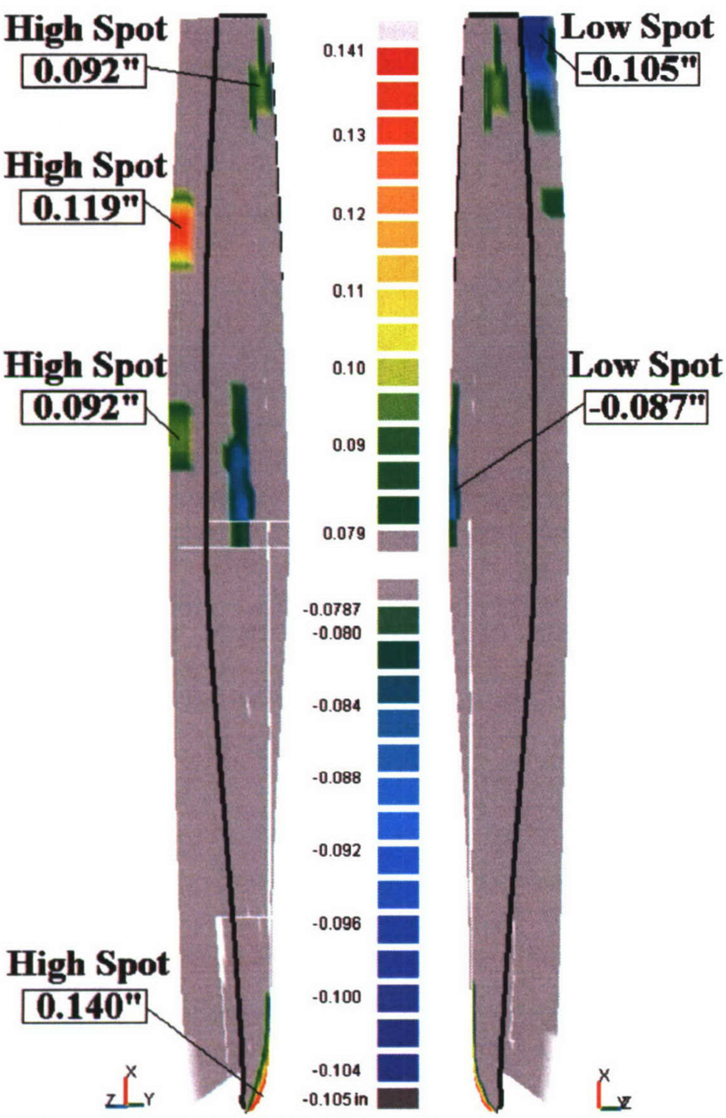


Figure D5. Model 5662-1: Oblique view of port and starboard regions out of 2mm tolerance. The black line represents the waterline.

Model 5662-1: Areas out of tolerance

96.4% of the measured points below the waterline fall within ± 2mm (0.0787 in) of the CAD file. 96.7% of all of the measured points (~470,000 points) on the model fall within ± 2mm (0.0787 in) of the CAD file.

The maximum positive deviation from the measured points to the CAD file is 0.140 in. This high spot (shown as red in Figure D5) occurs in the bow region. The maximum negative deviation is -0.105 in., and occurs on the stbd side in the aft region (shown in blue). This indicates a low spot.

The gray regions are within the ± 2 mm (0.0787 in) tolerance.

Note:
The measured data was translated and rotated into this "best fit" position so that the deviations on each side of the hull would be somewhat symmetric, and so that the number of measured points below the waterline in tolerance would be maximized. It is important to note that the areas out of tolerance are depended on the best fit position of the model. The data was translated and rotated as one set, as one area of the model comes into tolerance, another area of the model may go out of tolerance. Although Model 5662 and Model 5662-1 share the same section from Station 10 and fwd, on Model 5662-1 there appears to be more deviation around the bow. This is simply because of the final best fit position which was chosen.

Model 5662-1: Transom

Figure D6 illustrates the fit on the transom. The gray regions are in the specified tolerance (± 2mm); the entire transom area is within the desired tolerance.

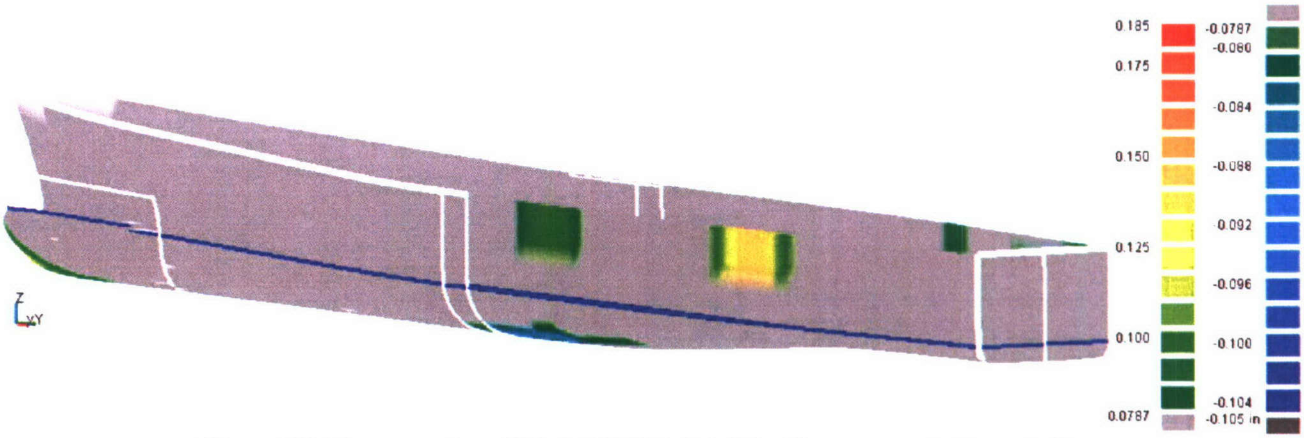


Figure D6. Transom view of Model 5662-1. The blue line represents the waterline.

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CALIBRATION CERTIFICATE
LASER TRACKER MODEL Xi

Date	**October 18, 2006**
Certification Number	**4651**
Tracker Serial Number	**L03000301102**
Customer	**Naval Surface Weapons Center** **9500 MacArthur Blvd** **West Bethesda, MD 28017**
Date Calibrated	**October 18, 2006**
Date Due	**October 18, 2007**
Certified By	Marie A. Sigmund **Marie A. Sigmund** **Lead Field Service Engineer**
Condition Found	**In Tolerance**
Condition Left	**In Tolerance**

The instrument listed above has been tested, inspected and compensated against FARO working standards that have been calibrated using National Institute of Standards and Technology (NIST) or other appropriate nationally or internationally recognized standards.

Calibrations conform to procedures developed in accordance with ISO-10012 and MIL-STD-45662A. Calibration results relate only to the items specified. This report shall not be reproduced except in full without the written consent of the FARO Technologies Laser Measurement Division.

FARO
Laser Measurement Division

Date	**October 18, 2006**
Certification Number	**4651**
Tracker Serial Number	**L03000301102**

Calibration Standards Traceability Data

HUMIDITY STANDARD

Honeywell Opto. RH Sensor Model IH 3602A
Serial Number: 02080816 – 237
Calibrated by Honeywell, Hycal Sensing Products

TEMPERATURE STANDARD

Cornerstone Sensors Inc. Model TA1041
Calibration Date: 15 March 2005
Calibrated by FARO Technologies
Calibration Standard: Hart Scientific Model 1521, Serial Number: A5C403
Last Calibration: 12/8/05 Next Calibration: 12/8/06
Trace Number: A5C09014

Allowable Deviation: ± 0.4°C as compared to Standard.

As Received (°C)			Post Calibration (°C)		
Standard	Actual	Deviation	Standard	Actual	Deviation
20.48	20.47	0.01	19.36	19.32	0.04

PRESSURE STANDARD

Vaisala Model PMB 100 Pressure Module
Serial Number: X2010020
Calibration Date: 15 March 2005
Calibrated by FARO Technologies.
Calibration Standard: Druck Model 740, Serial Number: 695/99-11
Last Calibration: 3/9/06 Next Calibration: 3/9/07
Trace Number: TN-261146

Allowable Deviation: ± 1.4 mmHg as compared to Standard.

As Received (mmHg)			Post Calibration (mmHg)		
Standard	Actual	Deviation	Standard	Actual	Deviation
759.44	759.43	0.01	748.61	748.49	0.12

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